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MEDIUM CARBON PEARLITIC MANGANESE STEELS

By Jerome Strauss

Abstract

This paper is devoted to a discussion of the metallurgical and mechanical characteristics of steel of 0.30 to 0.50 per cent carbon and 1.00 to 2.00 per cent manganese. Both wrought and cast forms are considered in both light and heavy sections. The author has pointed out the similarity of these steels to other structural alloy combinations, the limitations of heavy sections and of low tempering temperatures, as well as advantages in respect to cutting qualities, resistance to corrosion, and strength at moderate temperatures.

Introduction

RECENT years have witnessed an ever-increasing interest on the part of the metallurgical fraternity in alloy steels featuring the low-cost alloying elements silicon and manganese. With the objective in the production of finished metallic articles being generally that combination of raw material and processing operations resulting in the cheapest units that will render the desired service, there has been extended application of these inexpensive alloying additions to steels, particularly in such composition combinations as enable the user to secure high hardness with good ductility and thus replace or avoid more costly raw material.

Perhaps the largest tonnage of steels of this class made during the past five years, has contained manganese as the principal alloying element. While experimental work performed and contribu-

tions to the literature have recently been quite numerous in the lower carbon higher manganese ranges (10, 12, 21, 22, 24)[1], there has been greater commercial production, by far, in medium carbon, medium manganese steels. The author does not wish to infer that the latter are the more valuable types or that this relation in respect to volume of product is likely to continue but merely desires to present the facts as they exist at this time. For all these carbon-manganese steels, the foremost American proponent has been Hall (3, 4, 10, 12, 24) but his activity has been largely confined to their use in the cast state. Quite recently, however, several producers of rolled steel bars have manufactured manganese steels in quantity and their use in the form of hand forgings, drop forgings and articles machined directly from the bars has spread rapidly.

As previously noted, steels of low-carbon and moderately high manganese have been the subject of much study. They have generally contained less than 0.30 per cent carbon and with this proportion, useful steels may be obtained with up to 4.0 per cent or slightly more manganese. But productive effort is at present devoted largely to steels with manganese under 2.0 per cent and this paper is concerned with such steels (1.0 to 2.0 per cent manganese) within the carbon range of 0.30 to 0.50 per cent. Lower carbon steels of this manganese content are also being applied in many fields, both for carburized parts and for pressings, forgings, etc., subject to other types of heat treatment, but they will be omitted from this discussion.

THERMAL TRANSFORMATIONS

A summary of published results obtained in studies of the transformation temperatures and structures in pearlitic manganese steels (1, 6, 8, 14, 21), with due regard for probable accuracy of the methods employed, yields the data tabulated below:[2]

Ac_1 — Lowered 11 degrees Fahr. (6 degrees Cent.) per 1 per cent increase in manganese.

Ac_3 — Lowered 116 degrees Fahr. (60 degrees Cent.) per 1 per cent increase in manganese up to 1 per cent, and very little change (possibly 3 to 6 degrees Cent.—6 to 11 degrees Fahr.—per 1 per cent increase in manganese) up to 3 per cent manganese.

Ar_3 — Lowered 125 degrees Fahr. (70 degrees Cent.) per 1 per cent increase in manganese.

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[1] The figures appearing in parentheses have reference to the bibliography appended to this paper.

[2] Mention is here made of lower carbon steels in order that the picture may be complete.

Table I
Compositions of Steels Used

Type	Serial No.	Origin	C	Si	S	P	COMPOSITION—Per Cent					
							Mn	Ni	Cr	Mo	V	Cu
Carbon	489	Unknown	.41	.20	.031	.021	.67	none	none	....	....	.16
	239	Unknown	.55	.08	.044	.022	.36	none	.04	....	....	.11
	W	Unknown	.61	.30	.030	.010	.55	none	.02	....	....	.12
	264	Unknown	.65	.18	.039	.018	.65	.16	.05	....	....	.06
Manganese	B	Basic O.H.	.44	.14	.038	.020	1.05	none	none	....	....	.12
	283	Unknown	.45	.10	.027	.027	1.09	.18	.06	....	....	.09
	A	Basic O.H.	.48	.20	.035	.018	1.09	.10	.08	....	....	.12
	471	Basic O.H.	.46	.19	.032	.021	1.12	none	none	....	....	.10
	Z	Basic O.H.	.49	.15	.023	.016	1.13	none	none	....	....	.06
	506	Basic O.H.	.51	.31	.037	.021	1.17	.24	none	....	....	.04
	624	Basic Elect.	.35	.16	.014	.015	1.17	.30	.06	....	....	.14
	625	Basic Elect.	.32	.15	.010	.029	1.31	.33	.09	....	....	.09
	626	Basic Elect.	.33	.12	.010	.024	1.34	.37	.09	....	....	.17
	451	Basic O.H.	.51	.23	.024	.029	1.35	trace	.08	....	....	.02
	221	Unknown	.35	.04	.055	.078	1.43	.32	.07	....	....	.08
	604	Basic O.H.	.38	.10	.103	.019	1.75	none	none	....	....	.22
	458	Basic O.H.	.34	.23	.026	.020	1.88	none	none	....	....	.10
	459	Basic O.H.	.47	.30	.035	.022	2.12	.07	none	....	....	.16
Nickel	S	Basic Elect.	.25	.28	.040	.021	.68	1.97	....	....	....	.26
	200	Basic Elect.	.27	.32	.016	.035	.92	3.61	....	....	....	.27
	470	Basic Elect.	.30	.32	.025	.035	.94	3.43	....	....	....	.28
	486	Basic Elect.	.23	.17	.030	.031	.61	4.61	....	....	....	.32
	D	Basic Elect.	.31	.27	.025	.022	.77	3.31	....	....	....	.30
	X	Basic Elect.	.34	.28	.035	.030	.65	3.48	....	....	....	.26
	C	Acid O.H.	.41	.30	.028	.041	.71	3.02	....	....	....	.24
Chromium-Nickel	467	Unknown	.40	.18	.020	.012	.60	1.81	1.05	....	....	.10
	460	Basic Elect.	.44	.29	.012	.013	.43	2.10	1.00	....	....	.16
	266	Unknown	.42	.20	.031	.008	.25	3.03	1.32	....	....	.08
Chromium-Molybdenum	490	Basic O.H.	.55	.28	.022	.016	.76	trace	.93	none	....	.12
	500	Basic O.H.	.37	.20	.011	.026	.65	.06	1.07	.34	....	.06
Chromium-Vanadium	484	Basic O.H.	.30	.19	.025	.017	.70	none	.95	....	.15	.08

Ar_1 — Lowering variable but about 90 degrees Fahr. (50 degrees Cent.) per 1 per cent increase in manganese, being higher, the higher the actual manganese content.

With increase in carbon or manganese or both, the A_3 temperature, being more rapidly lowered than the A_1 temperature, ultimately overlaps the latter. With 0.20 per cent carbon this occurs at about 3.0 per cent manganese and with 0.40 per cent carbon at about 2.0 per cent manganese.

Obviously, the above involves a lowering of the eutectoid carbon content which appears to be about 0.78 per cent for 1.0 per cent manganese, 0.67 per cent for 2.0 per cent manganese and 0.50 per cent for 3.5 per cent manganese.

Increase in manganese also results in a widening of Ac_1 but available information is scarcely sufficient for generalization (with 0.40 per cent carbon and 2.0 per cent manganese slight hardening may occur when quenching from as low as 1230 degrees Fahr.—665 degrees Cent.)

The above values are averages of data of somewhat varied origin and as such must be considered as approximations when applied to practical problems, for the actual values will be influenced by many factors and will vary somewhat from melt to melt of similar composition.

One important feature, however, is the lowering of the thermal transformations on cooling, the practical importance of which has been frequently discussed[3] but not generally applied. The ability of these steels to harden at temperatures below the usual hardening temperature, subsequent to slow cooling from the latter temperature, is shown in Table II. Similar results for other common structural alloy steels whose compositions are listed in Table I, accompany the data on the manganese steels. These hardness tests were obtained on 1-inch diameter disks, ½ inch thick, heated to the maximum temperature shown in the table, cooled in the furnace at approximately 2 degrees Fahr. (1.1 degrees Cent.) per minute and quenched from the temperatures indicated.

That the tension and impact properties do not suffer from this method of heat treatment is illustrated in Table III, (except that the lower quenching temperature for Serial No. 604 was about 25 degrees Fahr. too low).

MECHANICAL PROPERTIES—SMALL SECTIONS

For these tests forged bars 1 inch in diameter were used. Determination of the properties resulting from annealing or quenching and subsequently tempering to 900 degrees Fahr. (480 degrees

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[3] B. Egeberg, "Neglected Phenomenon in Heat Treatment," TRANSACTIONS, American Society for Steel Treating, Vol. XII, No. 1, 1927, p. 46.

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Table II

Hardness of Steels Quenched from Temperatures Below A₃

Quenching Temp. deg. F	Serial 489 C-0.41	Serial 283 C-0.55	Serial 458 C-0.34 Mn-1.88	Serial 200 C-0.27 Ni-3.61	Serial 486 C-0.23 Ni-4.61	Serial 460 C-0.44 Ni-2.10 Cr-1.00	Serial 266 C-0.42 Ni-3.03 Cr-1.32	Serial 490 C-0.55 Cr-0.93	Serial 500 C-0.37 Cr-1.07 Mo-0.34
1550	44.3	52.3	51.3	48.0	....	....	....	57.0	53.3
1450	45.3	51.0	50.0	47.0	42.0	50.5	50.0	56.3	50.0
1400	43.7	56.3	51.6	48.0	43.0	51.5	48.7	55.7	51.7
1350	44.0	52.7	51.8	50.0	43.7	51.7	50.0	57.7	50.0
1300	39.0	53.3	49.6	48.6	43.3	51.6	52.7	49.7	42.0
1250	32.0	44.0	49.5	48.0	44.3	53.7	51.3	18.3	7.0
1200	1.7	11.3	52.0	48.3	46.3	32.7	50.7	18.0	6.6
1150	2.0	8.3	40.6	48.3	46.6	18.3	9.3	....	7.0
1100	2.0	10.6	37.0	48.7	45.3	17.3	9.6	12.0	7.6
1050	....	....	....	....	35.0	8.7	9.7	11.3	....

Table III

Tension and Impact Tests of Manganese Steels Quenched From Between Ac₃ and Ar₃
All Bars Tempered 900 Degrees Fahr. after Quenching

Type	Serial No.	Initial Heating Temp. °F	Quench Temp. °F	Prop. Limit lbs./sq. in.	Tens. Strength lbs./sq. in.	Elong. % in 2"	Reduct. Area %	Izod Impact ft. lbs.
Carbon	489	1500	1500	76,400	112,500	23.1	63.4	76.5
		1500	1400	71,500	107,900	24.4	62.0	77.1
	264	1500	1500	105,700	158,900	14.6	39.0	5.5
		1500	1400	101,900	156,400	15.3	40.6	6.1
Manganese	506	1500	1500	101,900	144,100	17.5	53.2	62.5
		1500	1350	109,500	142,800	17.1	52.6	62.6
	604	1500	1500	112,000	144,100	15.5	51.0	51.5
		1500	1250	86,600	133,600	13.3	37.3	41.8
Nickel	200	1500	1500	130,400	149,700	17.9	56.0	37.8
		1500	1150	130,100	148,900	17.3	56.1	36.0
	486	1450	1450	127,600	142,100	18.3	58.9	48.1
		1450	1150	123,500	141,500	18.8	58.4	45.6
Chromium-Nickel	266	1450	1450	142,600	180,700	14.6	50.7	32.9
		1450	1250	145,200	182,700	14.2	50.6	34.5

Cent.) or higher were made on bars completely heat treated before machining. The tension test bars were ½ inch in diameter with a 2-inch gage length and threaded ends; the Izod impact test bars were 10 millimeters square with Mesnager type notch (drilled hole 2 millimeter diameter with center 1 millimeter below surface), two notches to the 4-inch long bar. When quenching with subsequent tempering below 900 degrees Fahr. (480 degrees Cent.) was employed the 1-inch bars were rough machined prior to heat treatment leaving 0.03 inch on the diameter of the shouldered ½ inch by 2 inch tension test bars and 0.04 inch on the thickness of the Mesnager type impact bars (except at the drilled hole which was finished), to be ground off after treatment. This permits a better study of the properties of steels when used for gears, springs and other parts similarly processed.

The bars treated as 1-inch rounds were annealed at 1450-1500 degrees Fahr. prior to treatment. Those treated after roughing out were normalized and annealed prior to this machining (as for the steels of Table IV).

Rather than reproduce in tabular form all of the test results of this group, they have been assembled in the accompanying charts Figs. 1 to 5 inclusive. The properties obtained for tensile strengths of 110,000-135,000-175,000-200,000-225,000 pounds per square inch are reported graphically. The values plotted are the results of interpolation between averages of two tension tests and four impact tests for each heat treatment. Extrapolation of the curves was used to a very limited degree and only when such extensions were small and of assured reliability. No interpolations were attempted between results obtained on bars 1 inch round as treated and those treated after rough machining due to the influence of size of section upon the quenching effect, especially in steels which do not harden deeply. Values are omitted in the charts where they have been unattainable with the particular steels, or due to shortage of material, or in a few cases due to availability only by interpolation between tests on different cross-sections as just noted. The results for 200,000 pounds per square inch tensile strength and over were all obtained on the rough machined bars.

Tests on annealed bars appear in Table IV. The unusual results on the annealed nickel steel, Serial No. 200, have been observed in a few other melts; the cause is not definitely known but the

Table IV

Tension and Impact Tests of Annealed Steels

All Bars Normalized (air-cooled) 125 to 150 Degrees Fahr. above the Annealing Temperature, before Annealing

Type	Serial No.	Prop. Lt. lbs./sq. in.	Tens. Str. lbs./sq. in.	Elong. % in 2"	Reduct. Area %	Fracture	Izod-Impact ft. lbs.	Hardness Rockwell O/150
Carbon	489	38,200	80,100	31.9	55.6	.6 cup	55.1	−1.8
	264	35,700	101,100	21.6	34.6	Ir. S & Cry.	15.0	11.5
Manganese	283	39,500	96,400	24.4	43.7	.6 cup	27.8	7.5
	506	51,000	106,200	24.2	47.3	.6 cup	27.5	14.6
	604	42,100	89,800	28.2	57.2	.6 cup	62.9	6.5
	458	54,800	97,000	27.5	63.9	.7 cup	62.6	10.5
Nickel	200	36,900	134,800	19.3	31.8	.5 cup	18.9	26.1
	486	36,000	105,300	25.4	52.3	.5 cup	38.3	15.1
Chromium-Nickel	266	57,300	112,000	23.9	59.0	.6 cup	56.8	17.5
Chromium	490	38,200	109,500	19.0	37.1	S. Sl. Cry.	20.8	16.0
Chromium-Vanadium	484	39,600	82,000	30.3	60.9	.7 cup	78.0	1.7

properties resulting on quenching and tempering are not in any way unusual, whereas ordinary slow cooling from the annealing temperature appears to effect slight hardening.

Although comparisons of any two of the steels studied rarely show superiority in all properties, of one steel over another, it becomes immediately recognizable that the manganese steels, and especially those higher in this added element, are more closely allied in their mechanical properties, to the other structural alloy steels, than to the carbon steels. In emphasizing their desirable features, comparisons have usually been made with carbon steels, but it is obvious that they are in the class of alloy steels, not only by reason of composition but due to their mechanical properties as well. It is also of interest that neither moderately high phosphorus (Serial No. 221) nor moderately high sulphur (Serial No. 604) adversely affect the strength and toughness of these steels.

In connection with all these comparisons it should not be forgotten of course, that melts of practically identical composition made at different times by ostensibly the same method, or by different methods, may show somewhat different properties or response to thermal treatment; small differences in properties between different steels reported here must therefore not be given too great significance.

As a result of the efforts of Hall and others the association of ''brittleness'' with the use in steels of manganese above 1 per cent, has almost vanished. In some quarters, however, these thoughts though not expressed, have not been completely dispersed. It is desired therefore to add one additional item of evidence against the ''brittleness theory.'' Steels showing undue sensitiveness when quenching sufficiently rapidly to produce high hardness, might be expected to show deterioration in ductility or impact resistance or quite readily crack when quenched after overheating. A few tests were therefore made in the manner described at the beginning of this section, using a quenching temperature 200 degrees Fahr. higher than that usually employed and which resulted in the data of Figs. 1 to 5 inclusive. A comparison of some of this data with that used in developing the above graphs appears in Table V.

The deterioration in properties due to the overheating is no greater than in the other alloy steels (in many cases of both no deterioration occurs at all) and the losses by cracking were no

Fig. 1—Chart of Properties of Heat Treated Steels of Compositions Shown, for Tensile Strength of 110,000 Pounds per Square Inch.

Fig. 2—Chart of Properties of Heat Treated Steels of Compositions Shown, for Tensile Strength of 135,000 Pounds per Square Inch.

greater for the manganese steels quenched in water than for the chromium-nickel steels quenched in oil and far less than for the chromium steel quenched in water. An interesting feature of these tests, though of no direct import in respect to the manganese steel is the great and consistent increase in impact resistance of the 0.65 per cent carbon plain carbon steel due to the overheating for quenching.

It will be noted from Figs. 1 to 5 and Table V that the impact resistance of the manganese steels is, in the higher hardness ranges, somewhat below that of some of the other alloy steels. In an effort to improve this condition, certain preliminary treatments were

Table V

Influence of Overheating for Quenching

Type	Serial No.	Tens. Str. lbs./sq. in.	Usual Quen 200° F Overheating Elong. %	Impact-ft. lbs.	200° F. Overheating Elong. %	Impact-ft. lbs.	Decrease from Overheating % Elongation	Impact
Carbon	489	110,000	24.6	85.3	23.3	79.1	5.3	7.3
	239	110,000	20.8	32.9	20.3	27.1	2.4	17.6
	264	135,000	17.7	27.2	16.2	19.7	8.5	27.6
		110,000	24.0	43.3	22.2	57.1	7.5	*
		135,000	18.6	14.3	17.8	38.1	4.3	*
		175,000	12.8	8.2	11.1	24.3	13.3	*
Manganese	283	110,000	24.4	85.3	23.5	82.0	3.7	3.8
	451	135,000	18.4	58.8	17.3	52.2	6.0	11.2
		110,000	26.1	86.8	25.2	86.1	3.4	0.8
		135,000	19.9	57.9	18.2	49.8	8.5	14.0
	604	175,000	11.8	26.6	10.3	23.6	12.7	11.3
		110,000	22.6	77.6	22.3	78.2	1.3	4.0
	458	135,000	18.1	60.4	16.8	58.0	7.2	*
		110,000	23.3	88.7	23.7	91.2	*	4.0
	459	135,000	17.6	67.8	17.9	55.0	*	23.3
		110,000	23.0	72.9	23.5	82.0	*	*
		135,000	19.2	39.2	18.2	43.6	5.2	*
		175,000	10.3	26.3	12.1	20.9	*	20.5
Nickel	200	110,000	25.2	101.0	26.7	104.5	*	*
	436	135,000	20.6	64.6	19.1	62.6	7.3	3.1
		110,000	26.8	91.2	27.3	86.8	4.0	4.8
		135,000	20.0	54.2	19.2	53.5	4.0	1.3
Chromium-Nickel	460	135,000	21.0	78.5	20.3	79.9	3.3	*
	266	175,000	14.4	36.0	15.1	24.0	*	33.3
		185,000	20.3	65.3	21.0	61.9	*	5.2
		175,000	14.1	39.7	14.4	36.4	*	8.3
Chromium	490	135,000	20.9	79.4	19.5	73.7	6.7	7.2
		175,000	15.4	46.4	12.2	33.0	20.8	28.9
Chromium-Molybdenum	500	135,000	20.1	91.4	20.4	84.5	*	7.6
		175,000	15.2	56.9	15.4	52.8	*	7.3
Chromium-Vanadium	484	135,000	18.3	75.7	19.6	85.4	*	*
		175,000	12.8	53.5	11.5	46.9	10.2	12.3

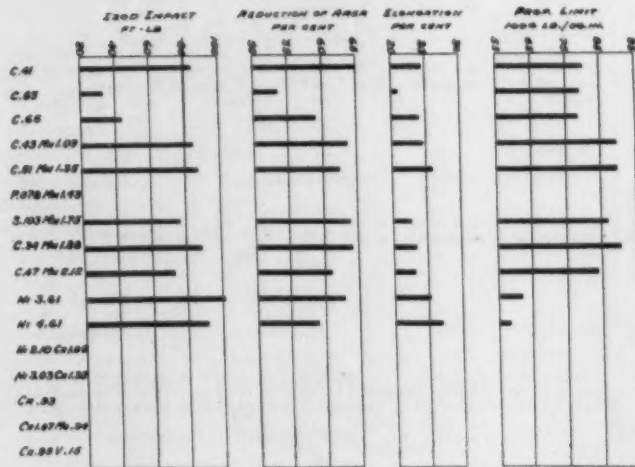(*) Increase in elongation or impact strength.
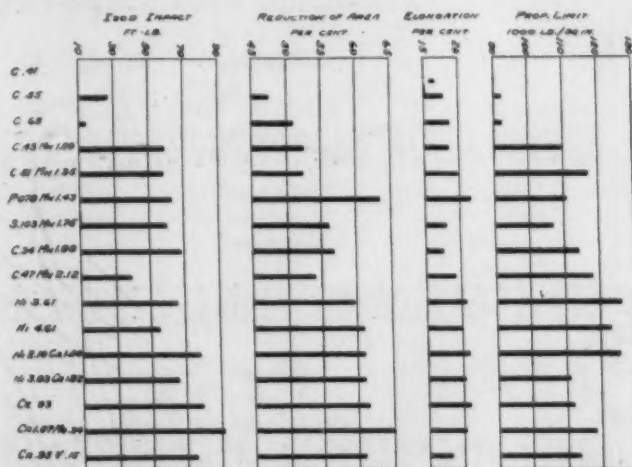
Fig. 3—Chart of Properties of Heat Treated Steels of Compositions Shown, for Tensile Strength of 175,000 Pounds per Square Inch.
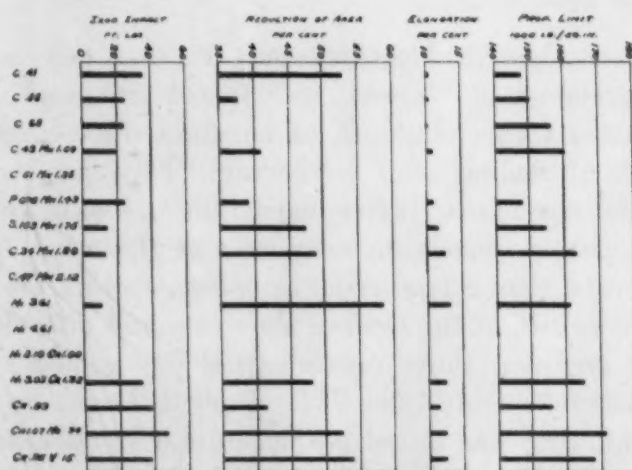
Fig. 4—Chart of Properties of Heat Treated Steels of Compositions Shown, for Tensile Strength of 200,000 Pounds per Square Inch.

applied to rough machined tension and impact bars, prior to the final quenching and tempering. These bars were first normalized, annealed and rough machined in the same manner as for similar bars previously described. The results obtained are recorded in Table VI, from which it is evident that no improvement has been secured from heat treatments of this type.

It has recently been reported (16) that increase in the manganese content of medium carbon steels leads to increased likelihood of temper brittleness, which becomes very marked at about 2 per cent manganese. The degree of susceptibility of some of the
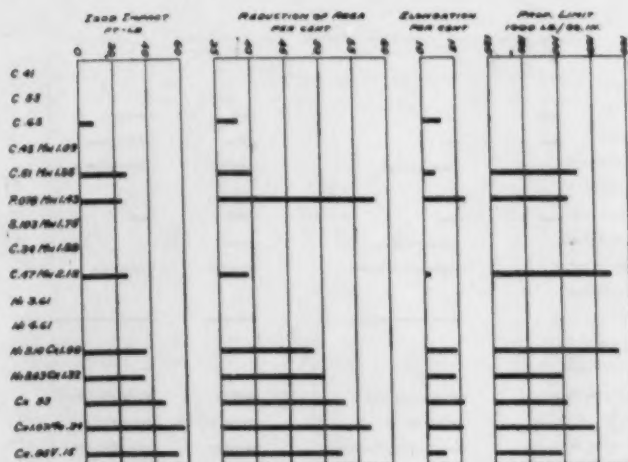
Fig. 5—Chart of Properties of Heat Treated Steels of Compositions Shown, for Tensile Strength of 225,000 Pounds per Square Inch.

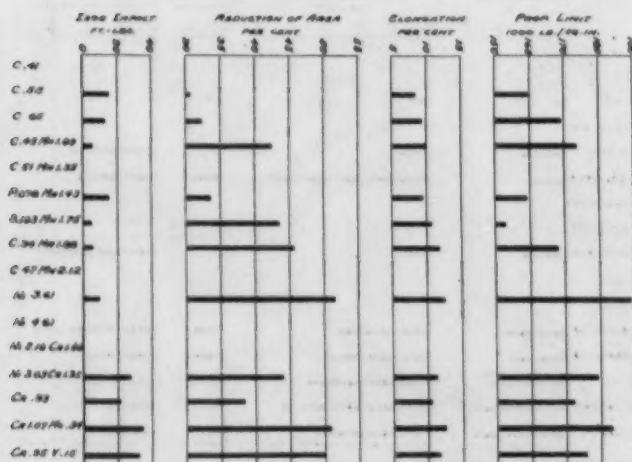manganese steels described in this report has been determined using a method developed by Greaves and Jones[4] for avoiding any influence upon the values obtained, of hardness differences resulting from the rate of cooling after tempering. This consists briefly in tempering the specimens (after hardening), cooling one-half of them in the chosen quenching medium and the other half at the desired slow rate, then retempering as before, cooling the specimens previously quenched, at the desired slow rate and quenching in the same chosen medium, those previously slowly cooled. The data secured are assembled in Table VII. Embrittlement on slow cooling after tempering was found but to quite a smaller degree than was anticipated. Chromium-nickel steels often show these effects and when testing by both the British standard notch and the Mesnager notch, ratios of impact strength in the tough and brittle states have been as high as 30 to 1. But that methods of manufacture can be adjusted to greatly reduce this susceptibility to temper brittleness is demonstrated by the fact that these steels are being produced continuously with ratios of 1.5 to 1 and even less. One of the best steels of this type that has come to the author's attention is listed in Table VII with a ratio of 1.11. Jones' values of the ratio for his crucible-made steels tested with the British standard notch (16) are 2.2 for a steel with 0.39 per cent carbon and 1.12 per cent manganese, and 18.5 for a steel with 0.36 per

[4] R. H. Greaves and J. J. A. Jones, "Temper-Brittleness of Nickel-Chromium Steels," *Journal*, Iron and Steel Institute, Vol. 102, Pt. II, 1920, p. 171.

Table VI

Influence of Complex Treatments on Impact Strength of Manganese Steels

All Bars Normalized 1600 Degrees Fahr. (30m) air, Annealed 1450 or 1475 Degrees Fahr. (30m) fce., before Rough Machining

Serial No.	C	Mn	Heat Treatment °F (min)	Prop. Lt. lbs./sq. in.	Tens. Str. lbs./sq. in.	Elong. % in 2"	Reduct. Area %	Izod Impact ft. lbs.
506	.51	1.17*	1650 (30) Oil 1475 (15) water 625 (90) Oil	210,700	265,300	8.4	31.1	1.6
			1650 (30) Oil 1475 (30) Oil 1200 (60) Fce 1475 (15) water 625 (90) Oil	206,500	261,400	9.3	33.1	2.0
604	.38	1.75**	1475 (30) water 625 (90) Oil	158,700	209,000	10.8	44.8	5.6
			1650 (30) Oil 1475 (15) water 625 (90) Oil	160,200	214,000	11.8	45.6	4.4
			1650 (30) Oil 1475 (30) Oil 1200 (60) Fce 1475 (15) water 625 (90) Oil	161,100	212,000	11.3	45.6	5.9
458	.34	1.88	1475 (30) water 625 (90) Oil	165,200	208,200	12.3	50.0	6.3
			1650 (30) Oil 1475 (15) water 625 (90) Oil	172,600	215,300	12.0	50.0	4.6
			1650 (30) Oil 1475 (30) Oil 1200 (60) fce 1475 (15) water 625 (90) Oil	168,700	211,500	11.8	47.8	8.8

*Ni—0.24   **S—0.103

Table VII
Temper-Brittleness Experiments
All Bars 1500 Degrees Fahr. (30 min.) Water, Prior to Tempering

Serial No.	Composition C	Mn.	Origin	Izod Impact (ft. lbs.) after second tempering at 1050° F and cooling: At 0.5° F per min.	By Water Quenching	Ratio Impact (quenched) Impact (slowly cooled)
283	.45	1.09	Unknown	43.5	60.8	1.40
471	.46	1.12	Basic O.H.	71.3	76.6	1.07
506	.51	1.17	Basic O.H.	49.3	53.3	1.08
626	.33	1.34	Basic Electric	49.4	58.5	1.19
604	.38	1.75	Basic O.H.	55.1	61.1	1.11
458	.34	1.88	Basic O.H.	30.5	64.0	2.10
266*	.42	Cr. Ni.	Unknown	50.5	56.0	1.11

*Heat treatment the same except that quenching for hardening was in oil and tempering was at 1080 degrees Fahr.

cent carbon and 2.24 per cent manganese. The maximum value of the ratio in the author's tests is 2.10 for a steel containing 0.34 per cent carbon and 1.88 per cent manganese and on the basis of recent studies[5], this value would not likely be above 3 to 3.5 had the sharper notch been employed in the test pieces. There is of course, an appreciable difference in manganese content but it should also be noted that the author's steel is of basic open-hearth origin and that this has generally resulted in steels of a given composition being far more temper brittle than those manufactured by the crucible process as was the case with the steels studied by Jones. It is obvious therefore that manufacturing methods may be influential in avoiding serious temper brittleness in manganese steels as in chromium-nickel steels. It is also pertinent to inquire whether the good results on the high-sulphur steel are due to composition or manufacturing procedure or both, but the question cannot be answered by the study of a single bar or melt.

MECHANICAL PROPERTIES—LARGE SECTIONS

The value of these manganese steels in quenched and tempered sections of moderate size was determined in two sets of experiments. In the first set, rough-turned cylinders of these steels and some of the other alloy steels previously used for comparative purposes, $3\frac{7}{8}$ inches in diameter and $5\frac{1}{2}$ inches long were quenched in the same quenching media as used in the earlier tests but from a temperature 50 degrees Fahr. (28 degrees Cent.) higher than that used for the 1-inch rounds; they were subsequently tempered at 900 degrees Fahr. (480 degrees Cent.). Tension and impact test speci-

[5]S. N. Petrenko, "Comparative Slow Bend and Impact Notched Bar Tests on Some Metals," TRANSACTIONS, American Society for Steel Treating, Vol. VIII, No. 5, 1925, p. 519.

mens and a slab for hardness measurements were cut in the manner shown in Fig. 6 The results of the tension, impact and hardness test appear in Table VIII.

The second group of tests was made on $5\frac{1}{8}$-inch rolled rounds of manganese steel and $5\frac{1}{8}$-inch forged rounds of nickel steel, all 12 inches long. Two different quenching temperatures were used to observe the effect of this variable upon the hardness
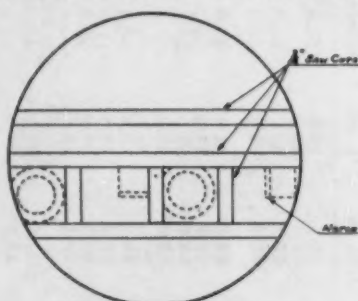

Fig. 6—Diagram Showing Locations of Test Specimens in $3\frac{7}{8}$-Inch and $5\frac{1}{8}$-Inch Bars.

gradient after treatment; all of the bars were tempered at 900 degrees Fahr. as in the earlier tests. Test material was cut in the manner indicated in Fig. 6; the Izod bars were of the usual dimensions and were taken from the center of the length but the tension test bars were made 8 inches long on the $\frac{1}{2}$-inch diameter gage length, to permit of greater precision in the determination of elastic properties. The data resulting from this series appear in Table IX.

More ready comparison of the results of these tests would have been possible had the bars been individually tempered to secure the same penetration hardness at the outer surface, but in spite of this it will be noted from the data in its present state that the manganese steels compare favorably with other structural alloy steels. Although inferior to some, in the maximum hardness obtainable and depth of penetration of surface hardness and to a smaller degree in elastic ratio, the ductility and resistance to impact are most favorable. The disadvantage in respect to elastic ratio at the center of large sections appears to grow rapidly with increase in cross section above about 4 inches.

CAST STEELS

Alloy steels of 1 to 2 per cent manganese with carbon con-

Table VIII

Tension, Impact and Hardness Tests of 3⅜-inch Rounds
All Bars Annealed 1450-1500 Degrees Fahr. after Forging

Type	Serial No.	Heat Treatment °F (min)	Bar Location	Prop. Lt. lbs./sq. in.	Tens. Str. lbs./sq. in.	Elong. % in 2"	Reduct. Area %	Izod-Impact ft. lbs.	Rockwell "C" Hardness Surface	Center	Distance from surface for drop of 2.0
Manganese	471	1500 (60) Water	Surface	101,500	143,200	18.0	50.7	70.0	32.8	....	3/16"
		900 (120) Oil	Center	81,500	130,600	19.3	51.0	38.8	....	27.7	
	458	1550 (60) Water	Surface	101,900	141,600	17.5	55.1	59.0	32.2	....	7/16"
		900 (120) Oil	Center	71,300	115,400	19.6	56.2	50.0	....	24.0	
Nickel	470	1500 (60) Water	Surface	117,100	148,700	12.8	33.8	33.0	34.6	....	(a)
		900 (120) Oil	Center	101,900	143,600	16.2	43.9	28.5	....	32.5	
	480	1450 (60) Oil	Surface	86,600	122,700	19.5	58.0	59.0	28.7	....	(a)
		900 (120) Oil	Center	81,500	122,200	18.8	53.2	47.0	....	26.4	
Chromium-Nickel	467	1550 (60) Oil	Surface	107,000	155,900	12.0	39.2	30.3	36.2	....	3/4"
		900 (120) Oil	Center	91,700	141,300	11.0	33.4	19.5	....	31.5	
	400	1550 (60) Oil	Surface	143,700	180,200	12.2	40.5	20.0	40.8	....	(a)
		900 (120) Oil	Center	122,300	176,000	12.5	40.1	11.5	....	39.3	
Chromium	490	1600 (60) Water	Surface	122,200	168,100	13.4	41.0	35.3	40.0	....	7/16"
		900 (120) Oil	Center	91,700	148,200	15.0	44.3	34.5	....	33.5	
Cr-Molybd.	500	1550 (60) Water	Surface	142,600	182,100	15.5	54.0	52.0	40.7	....	9/16"
		900 (120) Oil	Center	91,700	145,400	16.5	54.3	37.0	....	33.2	
Cr-Vanad.	484	1050 (60) Water	Surface	101,900	154,300	14.0	47.9	41.8	37.2	....	5/16"
		900 (120) Oil	Center	81,500	126,800	15.3	41.6	43.8	....	28.5	

(a) Hardened practically throughout.

Table IX

Tension, Impact and Hardness Tests of 5½-inch Rounds
All Bars Normalized at 1600 Degrees Fahr. (air-cooled) Before Treatment

Type	Serial No.	Heat Treatment °F (min.)	Bar Location	Prop. Lt. lbs./sq. in.	Tens. Str. lbs./sq. in.	Elong. % in 2"	Reduct. Area %	Izod-Impact ft. lbs.	Rockwell "C" Hardness Surface	Rockwell "C" Hardness Center	Distance from Surface for drop of 2.0
Manganese	B	1475 (60) Water	Surface	84,000	134,200	6.5	49.3	41.5	33.3	....	5/16"
		900 (120) Fce	Center	66,200	109,800	12.8	55.4	23.5	....	19.3	.....
		1525 (60) Water	Surface	81,500	150,500	9.0	41.3	45.0	34.2	....	3/16"
		900 (120) Fce	Center	63,700	135,700	10.5	41.6	44.8	....	24.0	.....
	A	1525 (60) Water	Surface	86,600	127,800	8.9	57.2	77.0	32.6	....	3/16"
		900 (120) Fce	Center	61,100	107,500	15.6	62.6	57.8	....	15.7	.....
		1575 (60) Water	Surface	91,700	127,800	10.0	55.6	68.0	31.3	....	1/8"
		900 (120) Fce	Center	81,500	104,100	15.3	60.3	68.0	....	16.6	.....
Nickel	D	1475 (60) Water	Surface	94,700	146,600	6.4	46.1	25.8	38.0	....	1/2"
		900 (120) Fce	Center	81,500	126,300	9.5	45.2	22.5	....	27.0	.....
		1525 (60) Water	Surface	99,700	136,200	4.8	47.4	26.5	36.6	....	1/2"
		900 (120) Fce	Center	86,600	125,000	8.1	51.3	37.8	....	25.7	.....
	C	1475 (60) Water	Surface	99,300	145,400	8.3	54.8	36.0	38.1	....	7/16"
		900 (120) Fce	Center	81,500	121,700	8.9	54.8	39.8	....	25.6	.....
		1525 (60) Water	Surface	104,400	143,900	9.0	52.1	29.0	36.1	....	9/16"
		900 (120) Fce	Center	76,400	117,600	12.8	47.3	28.5	....	22.5	.....

tent both below and above 0.30 per cent were produced commercially by Hall as early as 1909. Some of his more recent results upon these steels, with data on other steels for comparison (24), are reproduced in Table X. In Table XI appear mechanical properties obtained in the heat treatment of cast manganese and nickel steels in the author's laboratory[6]. The mechanical properties of these manganese steels are clearly equal to and sometimes better than those of the other steels examined.

These tests deal, of course, with only light sections of cast metal, 1 to 1½ inches thick. In heavier sections, steels of 1.50 per cent manganese or more may show appreciable segregations and coarse dendritic formations. The latter are particularly persistent and present a problem of some magnitude in the manufacture and treatment of these alloys.

MACHINING QUALITIES

One of the manganese steels reported upon in the tests of small wrought sections will be noted to contain one tenth of one per cent sulphur (Serial No. 604). Naturally with this composition, more than the usual amount of manganese sulphide is to be expected in the steel and the manufacturer reports the possibility of using cutting speeds almost as high as those for Bessemer screw stock and higher than those suitable for open-hearth screw stock, presumably for approximately the same tensile strengths. It is also maintained that the power required for cutting will be less on given operations than for either type of screw stock.

Rough turning tests were made of this steel and also of a higher carbon, somewhat lower manganese steel in comparison with a carbon steel and a nickel steel, all in two or more degrees of hardness. The tested material was in bars 3 to 3½ inches in diameter and 3 feet long; these were cut dry with ¼ by ½-inch tools with ⅛-inch nose radius and clearance 6 degrees, back slope 8 degrees, side slope 14 degrees, using a feed of 0.028 inch per revolution, and $\frac{3}{16}$-inch depth of cut in the manner described in an earlier paper[7]. The tools were of a high speed steel of the following composition:

C	Si	S	P	Mn	Cr	W	V	Ni
0.53	0.20	0.022	0.014	0.27	2.81	16.90	1.52	0.09

[6]The manganese steels of this table were manufactured at the U. S. Navy Yard, Norfolk, Virginia.

[7]H. J. French and Jerome Strauss, "Lathe Breakdown Tests of Some Modern High Speed Tool Steels," TRANSACTIONS, American Society for Steel Treating, Vol. II, No. 12, 1922, p. 1125.

Table X

Mechanical Properties of Cast Manganese and Other Steels
(J. H. Hall)

Type	C .32	Si	S	P	Mn .90	Ni	Cr	V	Heat Treatment °F (hrs.)	Elast. Limit lbs./sq. in. 58,750	Tens. Str. lbs./sq. in. 89,250	Elong. % in 2" 18.9	Reduct. Area % 24.8	Cold Bend deg. 70	Charpy Impact ft. lbs. 10.88
Carbon	.43	.21	.044	.039	.85	...	...	...	1650 (4) Slow	41,000	82,500	16.5	19.5	60	8.31
	.45	.21	.042	.040	.84	...	...	...	1650 (4) Air 1250 (6) Air	48,500	83,500	11.0	11.1	130	9.35
	.57	.35	.045	.037	.90	...	...	...	1650 (4) Slow	65,750	110,000	16.0	11.5	45	4.62
Manganese	.30	.27	.078	.047	1.62	...	...	...	1650 (4) Air 1250 (6) Air	48,500	91,000	25.5	44.9	180	11.98
	.31	.46	...	...	1.53	...	...	...	1650 (4) Water 1200 (6) Air	74,250	97,500	20.7	37.9	80	13.07
	.30	.54	...	...	1.81	...	...	...	1650 (4) Water 1200 (6) Air	75,000	95,800	22.2	43.8	70	20.35
	.33	.49	...	...	/1.80	...	...	...	1650 (4) Water 1200 (6) Air	84,890	119,700	17.4	26.3	70	16.98
Vanadium	.34	...	...	...	.85	...	...	.25	1650 (4) Water 1200 (6) Air	67,500	90,750	17.0	28.2	65	10.88
	.28	...	...	...	1.36	...	...	.18	1650 (4) Water 1200 (6) Air	75,500	103,000	22.3	42.2	80	19.80
Chromium-Nickel	.60	.33	.040	.041	.67	2.81	.92	...	1550 (4) Air 1250 (6) Slow	90,000	116,000	15.0	21.7	...	8.82

Table XI

Tests of Cast Manganese and Nickel Steels

Type	Serial No.	Heat Treatment °F (hrs.)	Prop. Limit lbs./sq. in.	Tens. Strength lbs./sq. in.	Elong. % in 2"	Reduct. Area %	Cold Bend deg. (*)	Izod Impact ft. lbs.
Manganese	625	1550 (2) fce, 1330 (1/2) fce	50,900	84,500	28.0	52.1	180	47.5
	625	1550 (2) fce, 1330 (1/2) fce, 1180 (24) fce	46,000	82,100	29.3	51.7	180	50.8
	624	1500 (1/2) Water, 1050 (1) Oil	81,500	118,400	18.0	40.7	150	52.3
	624	1500 (1/2) Water, 1200 (1) Oil	68,800	103,900	22.5	44.0	180	70.1
	626	1500 (1/2) Water, 1200 (1) Oil	62,200	98,500	24.2	57.2	180	78.6
	8	1600 (24) fce, 1380 (48) fce	44,300	79,400	28.8	42.5	145	....
Nickel	8	1600 (24) fce, 1380 (48) fce, 1200 (24) fce	30,600	78,300	29.0	46.7	180	38.0
	8	1600 (24) fce, 1500 (1/2) Water, 1050 (1) Oil	68,800	117,000	18.5	44.0	130	51.0
	8	1600 (24) fce, 1500 (1/2) Water, 1200 (1) Oil	58,600	101,600	22.3	49.6	130	49.0

(*) Bend bar 3/4"×3/8"×4-1/2"; bent over 3/4" pin.

Table XII

Data of Rough Turning Tests

Material Cut	Serial No.	Log No.	Prop. Limit lbs./sq. in.	Tens. Strength lbs./sq. in.	Elong. % in 2"	Reduction Area %	Cutting Speed ft./min.	Average Tool Life min.	Taylor Speed ft./min.	Average Power KW
Carbon	W	L-1	51,000	92,500	25.0	60.1	75	9.66	67.6	3.51
	W	L-2	51,900	105,700	20.6	50.4	70	6.13	59.0	3.26
Manganese	Z	E-3	45,800	94,500	26.5	50.2	75	7.79	65.6	3.33
	Z	E-1	66,200	111,000	25.5	63.5	70	3.87	55.3	3.22
	Z	E-1	66,200	111,000	25.5	63.5	75	2.81	56.6	3.48
	Z	E-2	81,500	138,800	16.2	43.7	45	9.20	40.0	2.29
	Z	E-2	81,500	134,500	20.0	55.6	43	9.47	38.6	2.49
	604	H-1	76,400	108,500	22.7	60.8	75	6.56	63.8	3.32
	604	H-2	91,700	137,500	16.2	50.2	45	14.47	42.9	2.23
Nickel	X	K-3	61,100	95,200	27.5	54.8	75	12.41	70.2	3.31
	X	K-2	81,500	113,300	23.5	62.8	75	3.90	59.3	3.45
	X	K-1	101,900	145,700	15.0	44.6	43	15.85	51.6	2.13

and were subjected to the heat treatment below:

Preheat	Preheat	High Heat	Quenched in	Tempered
1100 deg. Fahr. (30 min)	1600 deg. Fahr. (20 min)	2400 deg. Fahr. (3 min)	Oil	1060 deg. Fahr. (60 min)

From the results of these tests the Taylor speed, or the speed at which tool failure would occur after 20 minutes' cutting, was computed using the formula[8]:

$$VT^{\frac{1}{\text{'}}}=C$$

where   V=speed in feet per minute
T=time of cutting to failure at speed V.
C=Constant depending on material and cutting conditions.

The Taylor speed for the four steels is plotted against tensile strength in Fig. 7, while in Table XII are reported all of the data of these tests, including the power required for cutting.

Fig. 7 shows that in rough turning, the cutting tool will perform about equal work prior to failure when cutting the higher manganese high-sulphur steel as when cutting nickel steel of about 0.35 per cent carbon and 3.5 per cent nickel, the comparison being based upon equal tensile strengths. In like manner, the rough turning properties of the lower manganese steel and those of the carbon steel are quite similar and both produce more rapid failure of the cutting tool than do the first two steels considered. There are also included in Fig. 7 two curves (dotted) taken from a recent report on the rough turning of carbon and alloy steels[9]; the one to the left is of a 0.44 per cent carbon steel and the one to the right of a 3.5 per cent nickel steel. The former seems to bear little relation to the curve of the 0.61 per cent carbon steel included in the present tests, but there is a rough parallelism between the two curves of the nickel steels, thus affording a check upon the earlier determinations. The difference in the position of the two curves on the graph is probably associated with differences in the tool steels employed in the two groups of tests. The principal fact to be derived from this work, however, is that in rough turning, the high-sulphur higher manganese steel possesses no advantages over 3.5 per cent nickel steel but is considerably easier upon the cutting tools than steels with lower sulphur and lower manganese. Whether this difference in machining qualities is due to the sulphur content or

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[8] H. J. French and T. G. Digges, "Rough Turning with Particular Reference to the Steel Cut," American Society of Mechanical Engineers, Preprint, December 1926 Meeting.

[9] See foot note 8.

to the manganese content or to both, cannot be stated at this time but it is likely that each element exerts an important influence. It is of interest to note, further, that under the conditions employed
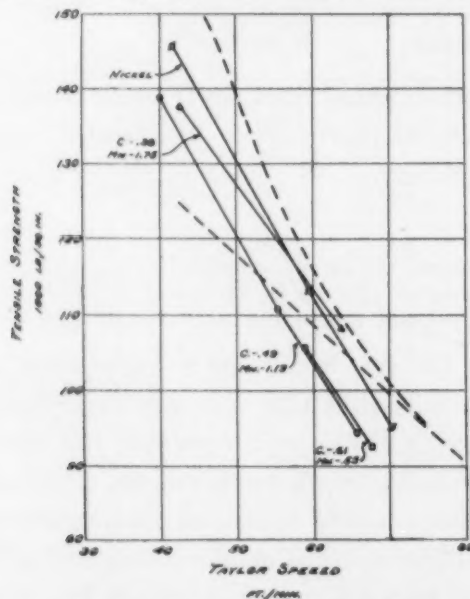

Fig. 7—Curves Showing Relation of Taylor Speed to Tensile Strength for Various Steels.

in the tests, the power consumed in cutting is related only to the cutting speed and not to the nature of the material being cut.

Whether these comparisons will hold good for milder cutting conditions such as generally used for finishing, cannot be discussed as no tests of this type have thus far been made. General experience and published work upon the subject would lead to the conclusion that data secured in rough turning could not safely be applied to operations involving milder cutting conditions.

OTHER PROPERTIES

Although satisfactory quantitative data does not appear in published literature it is generally recognized that these pearlitic manganese steels are appreciably more resistant to the attack of sea water and most natural waters, than are the carbon steels. This has resulted in widespread application of a steel of about 0.35 per cent carbon and 1.35 per cent manganese in the manufacture of cast steel anchor chain. Here it has rendered exceptional service due to the combination of corrosion resistance with high strength and ability to sustain suddenly applied stresses.

There has been notable comment in recent publications (25) of the ability of steels of about 1.5 per cent manganese to retain their strength properties at slightly elevated temperatures and this has led to their employment, largely in the form of bolts, in high pressure steam lines and other equipment operating at like temperatures. Strength data at high temperatures, however, are admittedly insufficiently complete to meet the needs of the designer or provide a satisfactory explanation of high-temperature phenomena for the metallurgist. Consequently, until our knowledge of both testing conditions and materials is further advanced, the limits within which these manganese steels may be serviceably and economically applied to high-temperature equipment, cannot be definitely stated.

Some study of the degree of segregation in these manganese steels, has been made on the materials referred to in this report. A portion of the analyses obtained appear below:

Serial No.	471		458		604		
	C	Mn	C	Mn	C	S	Mn
Surface	0.47	1.12	0.35	1.91	0.47	0.111	1.81
¼" below					0.43		
½" below					0.40		
¾" below					0.38		
1" below					0.37		
Center	0.51	1.15	0.33	1.86	0.37	0.097	1.74
Average Sample	0.48	1.13	0.34	1.88	0.38	0.103	1.75
Bar Dia. (In.)	5 1/16		4		3		

The segregation in the lower manganese steel is in the direction usually encountered in carbon and many alloy steels and the degree is comparable with that occurring in well-made products. In the other two steels, however, the segregation is inverse and extremely pronounced in the high-sulphur product. It is pertinent to add that the first two steels were manufactured in the same plant.

SUMMARY

The following are the principal features that have been dealt with in this discussion:

1. The mechanical properties of these manganese steels on small sections place them in a class with the other structural alloy steels, with which they may be compared to advantage.

2. In the higher ranges of strength and hardness (200,000

pounds per square inch and over) the impact resistance is lower than for some other alloy steels and this fact has barred them from some applications.

3. In heavy sections, the manganese steels show very good resistance to impact, but do not harden deeply and have elastic ratios that are slightly low; the latter defect becomes of serious magnitude in sections above 4 inches.

4. Temper brittleness is displayed by some of these steels but may be effectively reduced, as in chromium-nickel steels, by proper attention to manufacturing methods.

5. In these steels, as cast, coarse dendritic formations are prone to occur in heavy sections if careful practice is not followed but with attention to details, exceptionally good mechanical properties are obtained, equal to or superior to those of many other alloy steels.

6. Rough turning tests have been reported upon but are insufficient to permit broad generalizations.

7. Corrosion resistance of the alloys is favorable as is also strength at slightly elevated temperatures.

8. Segregation in alloys containing close to 2 per cent of manganese has been noted in more than one case to be opposite to that generally found in other simple structural steels; namely elements other than iron concentrating near the surface rather than near the center of ingots and bars.

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21. V. N. KRIVOBOK, B. M. LARSEN, W. B. SKINKLE AND W. C. MASTERS, "Some Characteristics of Low-Carbon Manganese Steel," *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 75, 1927, p. 404.

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24. J. H. HALL, "Special Manganese Steels," *Foundry*, Vol. 55, 1927, p. 169.

25. A. E. WHITE AND C. L. CLARK, "Properties of Ferrous Metals at Elevated Temperatures as Determined by Short Time Tension and Expansion Tests," Paper at Dec., 1927, Meeting, American Society of Mechanical Engineers.

DISCUSSION

Written Discussion: By H. W. Graham, Jones & Laughlin Steel Corp., Pittsburgh.

The question has been raised as to the most suitable analysis of high-manganese steel for carburizing purposes. In this connection it may be of interest to know that a sub-committee of the Iron and Steel Division of the Society of Automotive Engineers Standardization committee, has proposed a specification for high-sulphur, high-manganese steel to be known as S. A. E. X 1315. The limits of this grade are: carbon 0.10 to 0.20 per cent, manganese 1.25 to 1.55 per cent, phosphorus 0.05 per cent and sulphur 0.08 to 0.13 per cent.

This specification has been officially adopted by the Society of Auto-

motive Engineers, and will appear in their next published list of specifica-
tions.

We were much interested in Mr. Strauss' figures on machinability,—
in fact matters of machinability have been of keen interest to us for years.
Mr. Strauss has in this investigation confined it to carbons in the range of
0.30 to 0.50 per cent. This is a useful contribution to our knowledge of
machinability, but it is nevertheless an entirely different affair from the
conditions that exist in machining lower carbon steels.

It is to be regretted that the information now available on the
machinability performance of lower carbon steels is relatively meager, and
it is to be hoped that Mr. Strauss or some other individuals or agencies can
take up the investigation of finished cuts in the grades of steel not ordi-
narily considered forging steel, in order that work in this class of material
can be tied in with the information already brought out by Taylor, French
and others.

Written Discussion: By W. H. Phillips, Molybdenum, Corp. of America,
Pittsburgh.

It has been a privilege to listen to such a well prepared paper which
Mr. Strauss has ably presented. I believe, however, that there is one point
which Mr. Strauss has not placed sufficient stress upon, and that is the prac-
tice involved in the manufacture of the manganese steels with which he
has been working. I assume that these steels are of the highest grade of
alloy steel practice, and it can in no way be construed as carbon steel ton-
nage quality.

While it is true that the alloying elements used in the manganese
steels are low in price, this is a comparatively small item entering into the
cost of the making of high grade alloy steels. The care and skill required
in the manufacture of high grade alloy steels represents a greater part of
the cost of the steel than the alloying elements used. I believe it is fair to
stress this point in considering the paper Mr. Strauss has presented.

Author's Closure: The comments of Mr. Graham are of interest, although
requiring no reply; mention was made in the paper to the effect that carbu-
rizing steels were excluded.

Respecting Mr. Phillips' discussion, it is probable that some of the
manganese steels were made by other than the best alloy steel practice. All
of the comparison steels were from high grade electric or open-hearth ingots.
While realizing the influence of melting, refining and teeming practices, it is
unsafe to discuss this upon the basis of a sharp separation of two groups
when actually there is no sharp distinction but rather a continuous variation
from one to the other. Furthermore if indifferent steel-making resulted in a
product advantageous in respect to both physical properties and service life,
there is little probability of improved practice not at least equalling these
results.

The writer is a strong supporter of ''quality'' steels, but merely wishes
to point out that the comparisons in the paper are not seriously influenced by
this factor. Furthermore, the price of alloying elements may often be of
importance in spite of the fact that the ''quality'' extra is greater.

X-RAYS AND THE CONSTITUENTS OF STAINLESS STEEL

By Edgar C. Bain

Abstract

This paper deals with the utilization of X-rays in the study of the fundamental nature of stainless steel. A general survey of the properties of the alloys in which chromium is utilized to develop rustlessness is offered and an attempt is made to explain the properties on the basis of the changes in the constituents present. The changes in the amounts and conditions of the crystalline phases responsible for hardness and rust-resistance as developed by a variety of quenching tempering operations have been followed by means of the X-rays. The information gleaned from the extensive study of one steel is used to illustrate the broad trends of the general class of steels. The correlation of the hardness, corrosion-resistance and crystal structure of the steel in some sixty conditions of heat treatment presented here enables some conclusions to be formed with reasonable assurance.

The particular steel used here as an example is representative of a number investigated at the Union Carbide and Carbon Research Laboratories. This steel[1]— of the chromium rustless class—is of the higher carbon type capable of substantial hardening, and the results are applicable in the main to all similar steels of this type.

I. General

Corrosion-Resistance of Iron-Chromium Alloys

BY way of introduction, a few words reviewing the general aspects of corrosion[2] may be pertinent. Regardless of the precise atomic processes by which atmospheric corrosion of metals takes

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[1]This particular steel is from an experimental heat made in accordance with commercial practice obtained from Henry Disston and Sons, Philadelphia. The use of the material is gratefully acknowledged.

[2]Information from various sources which has been verified by the author is introduced here. The reader is referred to Benedick's and Sundberg's "Electrochemical Potentials of Carbon and Chromium Steels," *Journal*, Iron and Steel Institute No. II, 1926, and Grube and Fleishbein's "Die Oberflächenveredlung der Metalle durch Diffusion," *Zeitung für Anorganische und Allgemeine Chemie,* Tammann Memorial Issue, 1926. Some of the substance of this conception was referred to by Dr. W. Guertler in his A. S. S. T. Lectures, 1926.

place it is, generally speaking, a chemical or an electrochemical reaction involving oxidation and an aqueous environment and hastened by the presence of acid. Oxygen is universally the agent combining ultimately with the metal. The extraordinary corrosion inhibition contributed to iron by the presence of chromium in solid solution is of a special kind in that oxygen itself seems to be necessary for the resistance offered to corrosion. There is a simpler mode of alloying metals to obtain improved corrosion-resistance in which a noble metal is dissolved in the less noble one, decreasing its combining activities. In this case the metal is more or less ennobled by actually lowering its solution pressure. Chromium seemingly offers a more effective protection by providing a complete and self-renewing coating for the metal through its action with the ever-present oxygen. Benedicks and others have contrasted this familiar corrosion-resistance with the behavior of iron-chromium alloys attacked by reagents in the complete absence of oxygen; his results point definitely to the conclusion that oxygen is involved in the development of a surface condition resistant to attack. However, little natural rusting or fruit-acid corrosion is free from oxygen influence and under such oxidizing conditions chromium exhibits its unique corrosion-resistance. Somewhat similar to the slow and moderately oxidizing action of atmospheric attack (involving carbonic acid and traces of active oxygen) is the attack by nitric acid. Depending upon the dilution, the acid will act either chiefly as an oxidizer or as a simple acid. In solutions of between 1 normal and 2 normal HNO_3 concentration the action is probably a fair approximation to atmospheric attack so far as chromium effect is concerned except, of course, much more rapid. Therefore, the nitric acid test is much used for rapid and approximate prediction of probable rustlessness in the chromium alloys. Corrosion effects herein described are based upon such comparative tests.

As chromium is added to pure iron in solid solution there is relatively little change in atmospheric attack until the chromium content reaches about 12 per cent,—one atom of chromium to seven of iron. The alloy series exhibits an abrupt break in attack at about this composition, and the increase in chromium from 10 to 12.5 per cent in well homogenized metal may be accompanied by a tenfold reduction in atmospheric or nitric acid attack. A series of substantially carbon-free alloys investigated by the author ex-

                   X-RAYS OF STAINLESS STEEL   29

hibited such an abrupt change from the corrodible to the resistance behavior at the one-in-eight atomic proportion.

When the carbon content of these alloys just rich enough in chromium to be rust-resisting is raised by a few tenths of a per cent it is observed that they are no longer rustless in the annealed state but must be quenched in order to bring out the chromium corrosion inhibition. As the carbon is increased in the alloys (to obtain greater hardness) they are more and more dependent upon increased chromium and heat treatment for rustlessness. Tempering at high temperature, by restoring more or less the annealed structure, lessens the resistance.

It is explained by Guertler that the presentation at the metal surface of this critical proportion of chromium atoms permits the formation, by union with available oxygen, of a peculiar oxide surface film which is not only continuous but completely impermeable. With iron alone or its dilute chromium solid solutions the oxide formed lacks the continuity or impermeability and this protection is not developed. At any rate the peculiar resistance of the metal surface by the presence of at least one atom in eight is well established and seems to be the most important first law of the rustless irons and stainless steels.

Hardenability of the Chromium-Iron Alloys

As was described by the author in an earlier publication[3], pure gamma iron can dissolve only about 13 per cent chromium, and the presence of chromium gradually narrows the range of temperature for the existence of austenite. The presence of carbon or nickel increases the amount of chromium which can be held in austenite. It should be remembered that without austenite there can be no hardening by martensite formation. The presence of considerable chromium alone in austenite enables it upon cooling to transform to martensite in somewhat the same manner that carbon facilitates this behavior except that such carbonless martensites lack the great hardness of carbon-steel martensite. Microscopically, it is very characteristic and will, for convenience, simply be termed martensite in this paper.

Thus, even very low carbon alloys containing from 8 per cent to about 14 per cent chromium are rendered wholly martensitic

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[3]"The Nature of the Alloys of Iron and Chromium." Transactions, American Society for Steel Treating, Vol. IX, January, 1926, page 9.

and somewhat harder by quenching from the austenite range. Even though the actual hardness obtained is small, nevertheless, structurally, the alloys are capable of the martensitic mode of hardening and for purposes of the present discussion will be regarded as belonging to the hardenable class in the limiting case. With 0.12 or 0.15 per cent carbon the 15-per cent chromium alloy is easily rendered wholly martensitic. Twenty-per cent chromium alloys are entirely hardenable with 0.50 per cent carbon present by slow air cooling. Indeed, there seems to be a ratio of chromium to carbon which just permits the alloy to be rendered austenitic at elevated temperature and hence martensitic after suitable quenching. This proper quenching rate depends upon the chromium content and may vary from a quench in water with 15 per cent chromium and 0.12 or 0.15 per cent carbon to an air cool with more than 20 per cent chromium and appropriate carbon. Roughly, the limiting chromium percentage for complete martensitic hardening with various carbon content can be expressed by an equation which may take the following form:

$$\text{Chromium} = 12.5 + 16 \text{ Carbon}$$

The factor 16 may perhaps be in error by several per cent but the order of magnitude is correct. When the carbon exceeds this ratio the alloy is harder and may be quenched more slowly to develop martensite and avoid preserving austenite. When the chromium exceeds this value greatly the alloy is not rendered wholly austenitic at any temperature but instead it remains in equilibrium with some ferrite. In such alloys the austenite, at quenching temperature, may contain most of the carbon and less chromium than the ferrite. Such alloys are not wholly hardenable, having the microstructure of under-heated hypoeutectoid carbon steel after quenching—ferrite and martensite. When the chromium far exceeds the limit mentioned there may be no austenite formed at elevated temperatures in reasonable time, the reason being that within the mass of metal no ferrite region can be formed which contains the properly low chromium content (13 per cent) to change to austenite upon heating. In such cases austenite can only form at the interface of the ferrite and a carbide particle and is therefore negligible in amount. A tentative diagram may therefore be drawn of the general type shown to represent the

various regions of composition as they are susceptible to hardening, as in Fig. 1.

To summarize then: (1) Chromium in excess of about 13 per cent is incompatible with austenite formation (and hence martensite) except as carbon is present to increase its solubiliy in gamma iron. (2) Chromium in excess of the amount which is
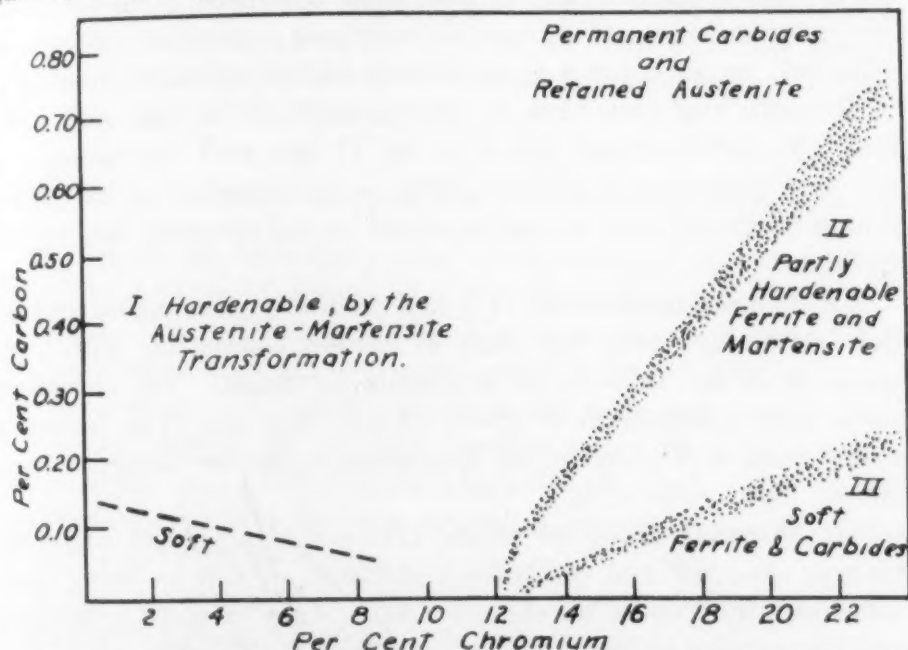

Fig. 1—Sketch Showing the Approximate Division of Iron-Chromium-Carbon Alloys into Metallographic Groups. The Lines are not Intended to Mark Compositions Sharply as in Equilibrium Diagrams. The Sketch is Based on Quenches from Sufficiently High Temperatures to Produce Maximum Austenite.

soluble in carbon-bearing austenite forms a permanent ferrite phase. (3) Very high chromium alloys form ferrite which remains practically in equilibrium with the carbide particles and form little or no austenite except at the vicinity of the carbide particles at very high temperatures. (4) In alloys wherein the ratio of chromium and carbon is such as to permit complete martensite formation, the hardness increases rapidly with carbon but is either unaffected or even slightly reduced by very high chromium. The amount of austenite retained after quenching increases with either higher carbon or chromium, and is very persistent.

Tempering tends, of course, gradually to restore annealed conditions in the alloys after quenching and the mode of the restoration will be discussed in this paper with the single typical steel as an example.

CLASSIFICATION OF THE RUSTLESS ALLOYS

I. There are available commercial rustless irons of two classes. (A) The one has a carbon content usually under 0.10 per cent and carries the minimum chromium content for corrosion-resistance (usually about 13 per cent). This alloy is improved for stainless-ness by quenching and is usually tempered somewhat. This heat treatment, by producing a martensitic structure, adds greatly to the strength and somewhat to the hardness of the material. The other (B) by carrying about 16 or 17 per cent chromium and scarcely higher carbon is not capable of any substantial hardening by heat treatment and is rust-inhibited in the annealed and softest condition.

II. The stainless steels (C) are definitely hardenable and al-most invariably carry the limit of carbon compatible with rust-resistance in the interest of maximum hardness. The chromium varies from a minimum of about 14 per cent up. The carbon is usually from 0.35 per cent up, depending upon the chromium con-tent.

III. Another group of alloys (D) possessing great high-tem-perature strength and oxidation-resistance as well as being rust-less is usually known as chrome iron. They contain ordinarily from 22 per cent chromium to 30 per cent with carbon up to 0.40 per cent. They are without structural transformation at any tem-perature short of about 2100 degrees Fahr. (1150 degrees Cent.) and recrystallize rapidly after cold work only at nearly 1830 degrees Fahr. (1000 degrees Cent.) Considerable time at very high tem-peratures causes only the development of a small amount of austen-ite in the vicinity of the carbide particles which ultimately gathers in the grain boundaries. These alloys are soft and ductile and en-tirely rustless, and not amenable to hardening by heat treatment. For the chrome irons and the second class of rustless iron there is a certain temperature which will develop the maximum austenite. If heated above this temperature the austenite will shrink to smaller regions. Whether or not the austenite formed at this elevated temperature persists or transforms to martensite with cooling de-pends upon the amount of chromium and carbon it contains and the rate of cooling; in the rustless irons it becomes martensitic after a quench while often it remains austenitic in the chrome-irons.

Probably a water quench in some cases yields more martensite and less austenite than a quench in oil.

There is another important family of chromium alloys which contain sufficient nickel to render them austenitic under all conditions. They possess all the properties of corrosion-resistance which their content of chromium would contribute in addition to ductility and oxidation-resistance. They are not hardenable. The present paper does not include discussion of these alloys, confining its scope to the iron-chromium-carbon alloys.

A Theory of Corrosion-Resistance, Hardening and Composition

A few of the deductions from many observations may be set forth with the hope of a generalization becoming apparent.

1. An iron solid solution containing an atomic proportion of more than about 12.5 per cent chromium either in alpha iron (ferrite) or gamma iron (austenite) is resistant to oxidizing acid or atmospheric attack. If the solid solution is not in a stable condition, as is the case in martensite, the rule still holds valid; indeed martensite, being a relatively active substance chemically, may possibly develop the protection even more thoroughly.

2. In the annealed or equilibrium condition iron-chromium-carbon alloys form a chromium-rich carbide. Such carbide contains essentially all the carbon of the alloy and a much higher ratio of chromium to iron than the ferrite in which it exists. Hence, carbide formation depletes the ferrite of chromium and if sufficient carbon is present the ferrite may have regions with insufficient chromium to resist corrosion even though the alloy as a whole may contain more chromium than the customary 12.5 per cent low limit.

3. In annealed alloys sufficient chromium must be present to satisfy the carbon-combining tendencies and enough more to render the ferrite resistant if the alloy is to be considered rustless. The regions in the ferrite immediately adjacent to growing carbide particles may be unduly depleted in chromium. Such regions may then show objectionable attack and render the entire surface subject to stain as far as appearance is concerned. The carbide particles act as unattacked inert particles.

4. The effect of heating and quenching therefore is to increase the proportion of chromium in useful form by dissolving the chromium-bearing carbide. The change to martensite of the austenite

thus formed prior to quenching does not again reduce the useful chromium content unless the carbide precipitation is brought about by insufficiently rapid cooling or by a tempering at too high a temperature. It is probable that tempering such rustless steel at a low temperature may at first form some Fe_3C (cementite) in preference to the chromium-rich carbide, due to the availability of iron atoms and the relative paucity of available chromium. This latter condition, however, is a transient one and of small importance.

5. The alloys in which there is a safe margin of chromium over that required for carbide formation and rich ferrite solution are not dependent upon quenching for rustlessness nor are they hardenable to any extent if this margin is large. If, however, the chromium–carbon ratio is not high enough for this condition, the quenching temperature must be sufficiently high to release the chromium from the carbide by solution in the austenite. There is, therefore, marked improvement brought about in the corrosion-resistance by the high quench. The hardness is also increased by the additional carbon dissolved at a high quenching temperature except the rate of quench and composition be such as to retain actual austenite, in which case the alloy will be softer and more resistant to attack. The rate of quench, temperature of quench and composition should be properly related for maximum hardness in stainless steel.

II. Properties of a Stainless Steel

The steel discussed herein showed the following analysis:

	Per Cent
Chromium	17.40
Carbon	0.77
Manganese	0.43
Silicon	0.25
Nickel	0.24

It was used in rolled sheet form 3/64 inch thick. A strip was quenched at each of the following temperatures: 1600 degrees Fahr. (870 degrees Cent.), 1700 Fahr. (930 degrees Cent.), 1800 degrees Fahr. (985 degrees Cent.), 1900 degrees Fahr. (1040 degrees Cent.) and 2000 degrees Fahr. (1095 degrees Cent.). Each strip was broken up into pieces and one specimen piece from each strip was tempered for one hour at the following temperatures: 480 degrees Fahr. (250 degrees Cent.), 525 degrees Fahr. (275 de-

grees Cent.), 575 degrees Fahr. (300 degrees Cent.), 615 degrees
Fahr. (325 degrees Cent.), 660 degrees Fahr. (350 degrees Cent.),
710 degrees Fahr. (375 degrees Cent.), 750 degrees Fahr. (400 degrees Cent.), 795 degrees Fahr. (425 degrees Cent.), 840 degrees
Fahr. (450 degrees Cent.), 930 degrees Fahr. (500 degrees Cent.)
and 1020 degrees Fahr. (550 degrees Cent.). The thin scale resulting from the heat treatment was removed by grinding with medium
abrasive papers.

EXPERIMENTAL METHODS

Several impressions were made upon each specimen with the
Rockwell hardness tester and the values averaged. The various
readings on one specimen all agreed closely. Experience shows
that only a slight error is introduced in the actual Rockwell hardness determination by the use of such thin specimens, and then only
in the softest condition.

Each specimen was prepared in the standard fashion for X-ray
crystallometry. A curved surface is ground and polished on the
edge of the sheet as described by McKeehan and this surface is
etched and repolished to insure representative metal being presented at the diffracting surface. A satisfactory degree of centricity is obtained in this manner and the greatest possible elimination of confusion in the lines is secured. The evidence for this
statement will be considered in the presentation of the X-ray
evidence.

After the specimens had been tested for hardness and crystal
nature they were carefully weighed and measured preparatory to
the nitric acid loss evaluation. The cleaned pieces were gently
moved about in a large volume of normal nitric acid solution for
two hours. This concentration of acid causes some slight loss in
weight with specimens of alloys which would be unattacked as far
as atmospheric corrosion is concerned. A stronger nitric acid solution would have shown practically no loss due to its greater oxidation tendency. The more dilute acid was chosen in order to extend
the attack into the more resistant conditions of the steel thereby
obtaining indications of trends even where detailed behaviors would
not ordinarily be observed. The contrast between the rustless and
rusting alloys is of course less marked than in stronger acids.

Hardness

The diagram in Fig. 2 shows the hardness obtained after quenching the steels in oil at various temperatures and reheating for an hour at a variety of temperatures. It will be seen that the hardness increases with quenching temperature up to the 1900 degrees Fahr. (1040 degrees Cent.) quench, due to the additional
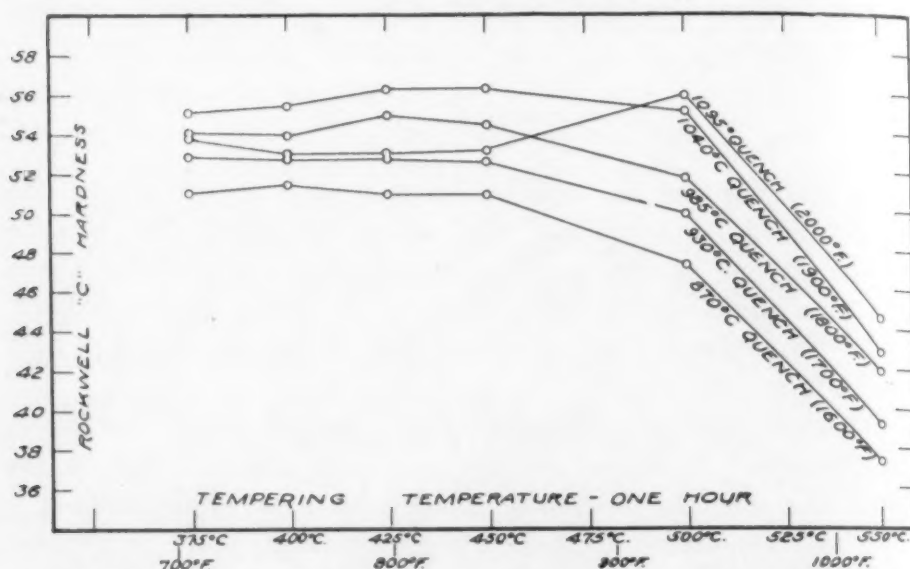
Fig. 2—The Hardness Obtained from a Stainless Steel with Various Heat Treatments.

carbon content of the austentite. The quench at still higher temperature, 2000 degrees Fahr. (1095 degrees Cent.), results in a reduction of hardness due to the development of austenite so rich in chromium and carbon (obtained from the carbides) as to be persistent after the quench.

For the lower quenches the hardness is essentially unaffected by tempering for an hour at 885 degrees Fahr. (475 degrees Cent.). This fact again calls to mind the tremendous effect of chromium to contribute high temperature strength and hardness. In this respect chromium stands second only to tungsten. For the very high quench which produces an exceedingly high chromium austenite we find in the diagram a clear development of definite secondary hardness. The relatively soft retained austenite decomposes to troostite (or martensite?) only completely at about 930 degrees Fahr. (500 degrees Cent.) and the steel then shows almost as great hardness as the material quenched for maximum hardness with no tempering.

It seems quite probable that there is a distinct difference between the formation of martensite in carbon and low alloy steels and its formation in the high alloy steels such as stainless and high speed steel. It appears always to lack the great intrinsic hardness, and the hardness of the slightly tempered or troostitic condition is almost as great as in the original martensitic condition. This may be due to the fact that the number of primary alpha iron nuclei formed in the cooling austenite is smaller and that the minutely distributed stresses are accordingly less severe.

CRYSTALLINITY AS DETERMINED BY X-RAYS

In this study of stainless steel only three crystalline entities or phases are involved: austenite or gamma-iron solid solutions, alpha-iron solid solutions—ferrite and martensite—and the complex carbide. The three fundamental materials each produce a characteristic assortment of X-ray diffraction bands on the Hull crystallogram. The assortment of bands or the "pattern" results from the peculiar atomic arrangement in the crystal of the material and is entirely characteristic. When two or three of the crystalline constituents are present, the crystallogram, of course, shows the patterns superimposed—the X-ray energy being distributed as far as photographic action is concerned, more or less proportionally to their concentration. There is not space here for an explanation of the phenomenon of X-ray diffraction nor of the method and technique of crystal analysis, but it will be quite easy for the reader to follow the conclusions as they are drawn by an inspection of the illustrations included herewith.

For this purpose, the only equipment really required is a set of diagrams of the line positions in the three characteristic patterns. The peculiar variation in the character of the various patterns should also be noted. In Fig. 3 is reproduced a set of such diagrams of X-ray patterns.

Diagram A is that of well-crystallized alpha iron. It will be observed that each diffraction band is drawn as two lines due to the fact that the characteristic wave-length used is actually a "doublet" composed of two wave-lengths of X-rays differing only slightly from each other. When the diffracting crystal is perfect as in well-annealed metals the doublet is resolved, but if the crystal is distorted or imperfect the diffrac-
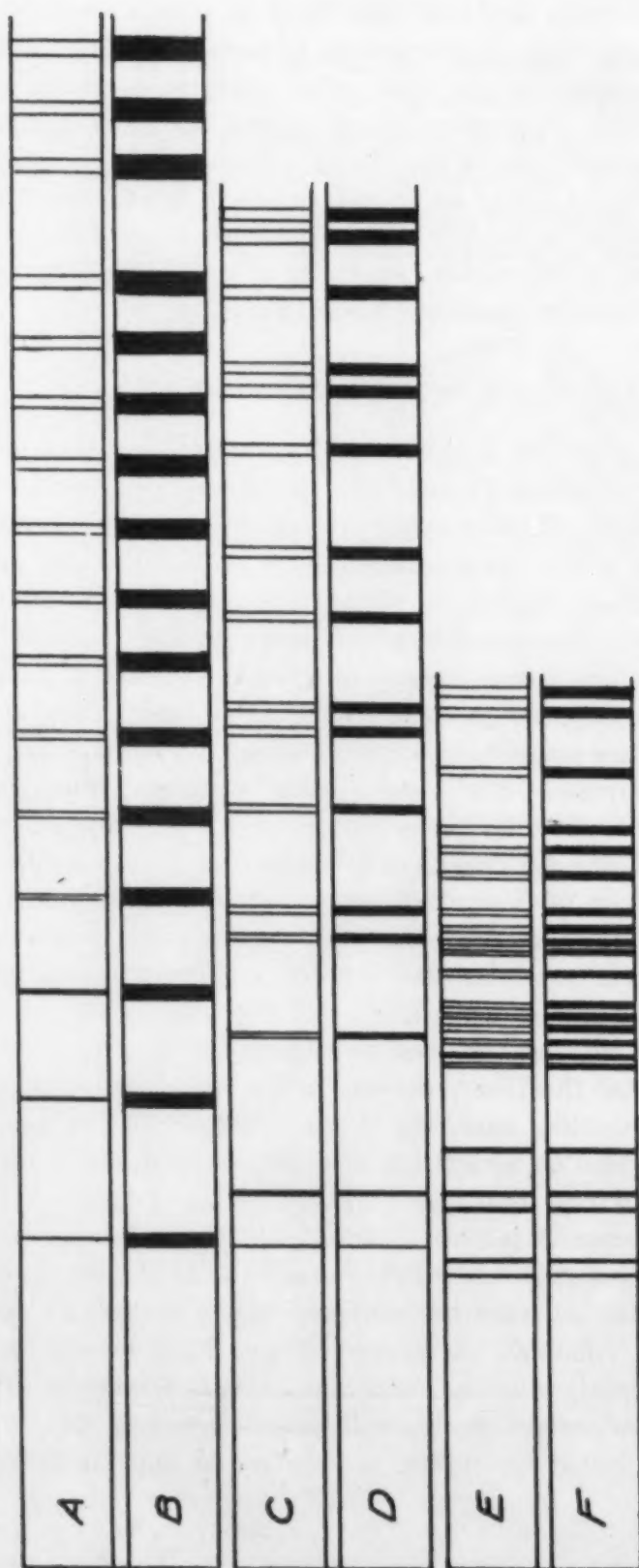
Fig. 3—Diagrams of the X-ray Patterns Obtained from the Constituents of Stainless Steel. Letters Refer to Text.

tion band is confused to such an extent as to obliterate the
doublet effect.

Diagram B is of alpha iron (or its solid solutions) in which
the crystals are distorted—either permanently or elastically.
Severe cold work produces almost such a pattern. Martensite
always yields the confused pattern and indeed the lines in the
diagram are not as broad as are customarily found in carbon
steel martensite. From stainless steel the martensite pattern
is usually less confused or broadened than for carbon or low
alloy steel.

Diagram C is of well-crystallized austenite typical of the
face-centered cubic form of crystal. Note that the first line
of the ferrite pattern almost but not exactly coincides with
the first austenite line.

Diagram D represents the width of lines from austenite
which is cold-worked or held elastically deformed by stress as
is the case in the austenite mixed with much martensite direct-
ly after quenching.

Diagram E is of the pattern of the complex carbide found
in stainless steel. It is entirely characteristic of high-chromium
steels although the exact concentration of chromium required
to produce this pattern instead of the cementite pattern is
not known.

Diagram F is representative of the kind of carbide lines
produced if the carbide is elastically deformed. This condition
is difficult to conceive of except perhaps in a very hard steel
containing residual carbide particles as freshly quenched. Very
fine particles of carbide would show a similar pattern.

Although the reproduction of the photographic films is
never very satisfactory a few typical patterns as recorded on
actual films are shown in Fig. 4.

A is a pattern of annealed ferrite (containing chromium)
showing the resolution of the alpha doublet, which forms the
test for perfection of crystallinity.

· B is a characteristic pattern of alpha iron in the marten-
sitic form found in high chromium alloys. Only moderate con-
fusion has resulted although the doublet is not resolved.

C is a pattern of martensite as formed in high carbon
steel. Note very great confusion.
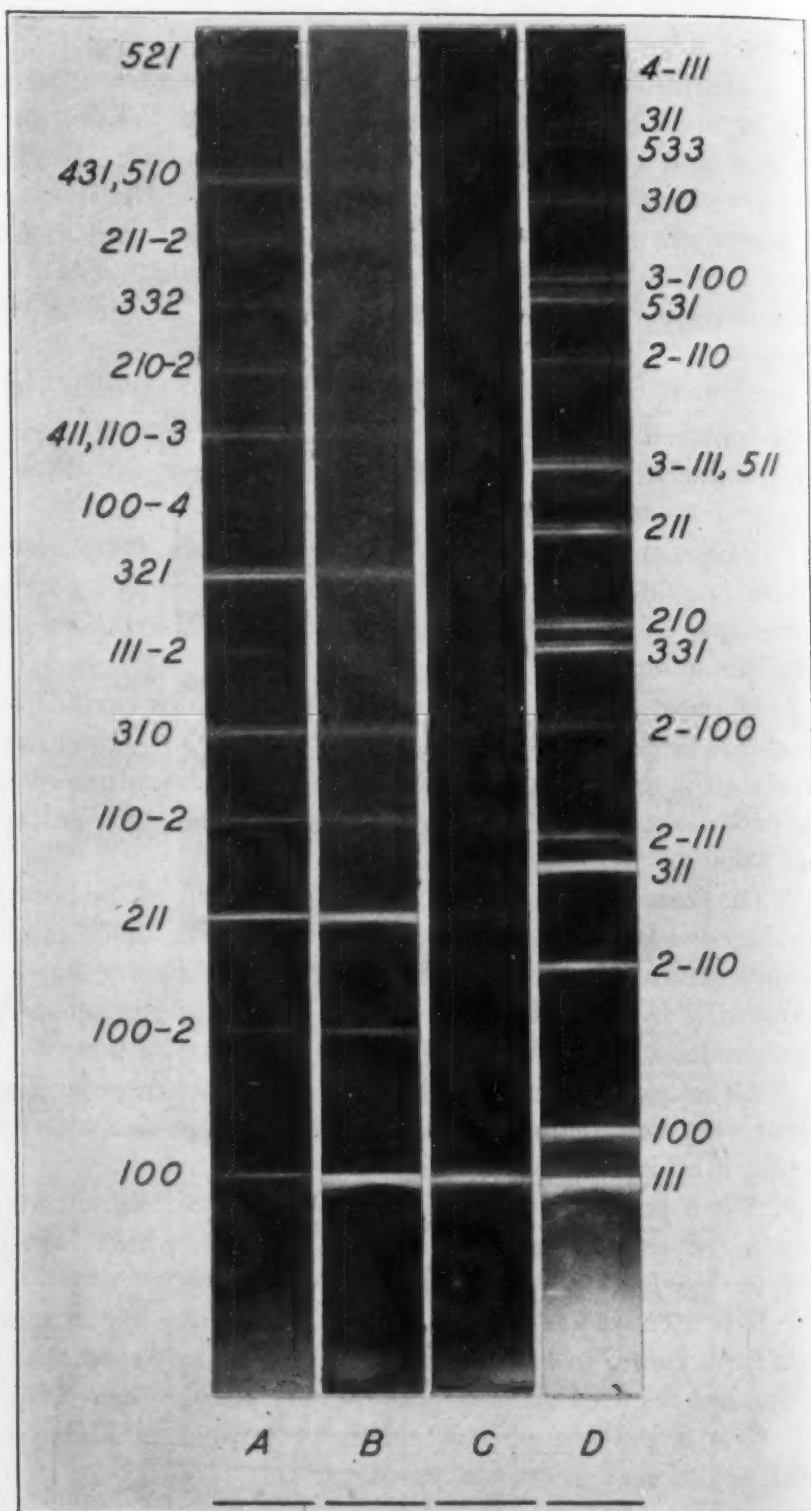
Fig. 4—Reproduction of the Actual X-ray Crystallogram Films for the Constituents Found in Steels.   Letters Refer to Text.

D is a pattern of well-crystallized austenite. This particular film was obtained from a high chromium-iron alloy in which just sufficient carbon and nickel were present to render it wholly austenitic.

The lines, then, found in these patterns constitute our qualitative X-ray tests for existence of the various constituents in the stainless steels. The relative strength of the patterns indicates the approximate proportion of the constituents.

The Figs. 5 to 9 inclusive are reproductions of the crystallograms obtained after various tempering treatments as indicated following the series of quenches. The Figs. 5, 6, and 7 of the changes by tempering following quenches at 1600 degrees Fahr. (870 degrees Cent.), 1700 degrees Fahr. (930 degrees Cent.) and 1800 degrees Fahr. (985 degrees Cent.) are similar. The crystallograms show conclusively that the carbide phase still persists to quite a degree and that essentially no austenite is retained after the quench. Tempering for an hour at temperatures up to 930 degrees Fahr. (500 degrees Cent.) causes almost no changes to result in the crystallograms. But tempering above this temperature 1020 degrees Fahr. (550 degrees Cent.) produces marked change. The resolution of the alpha doublet is quite perfect, which indicates the destruction of martensite and the release of practically all internal stresses. The temperature interval of 120 degrees Fahr. causes such complete change in the X-ray pattern that, in light of experience, we should know that considerable hardness was retained at 930 degrees Fahr. (500 degrees Cent.) and that a rapid softening occurred upon heating much above this point.

The group of patterns in Fig. 8 from the variously tempered 1900 degrees Fahr. (1040 degrees Cent.) quench specimens shows a distinctly lower carbide concentration than the lower quenches. Roughly, two-thirds of the original carbide seems to have been dissolved. In the low tempering treatments the faint austenite lines are to be seen and little change is observable up to a temper of 930 degrees Fahr. (500 degrees Cent.). At this temperature the martensite is destroyed and the stresses in the metal as well are released as shown by the excellent resolution of the doublet. The 1020-degree Fahr. (550 degrees Cent.) temper does not increase the intensity of the carbide lines, hence we may conclude that the precipitation is slight or of particles too small for observable dif-
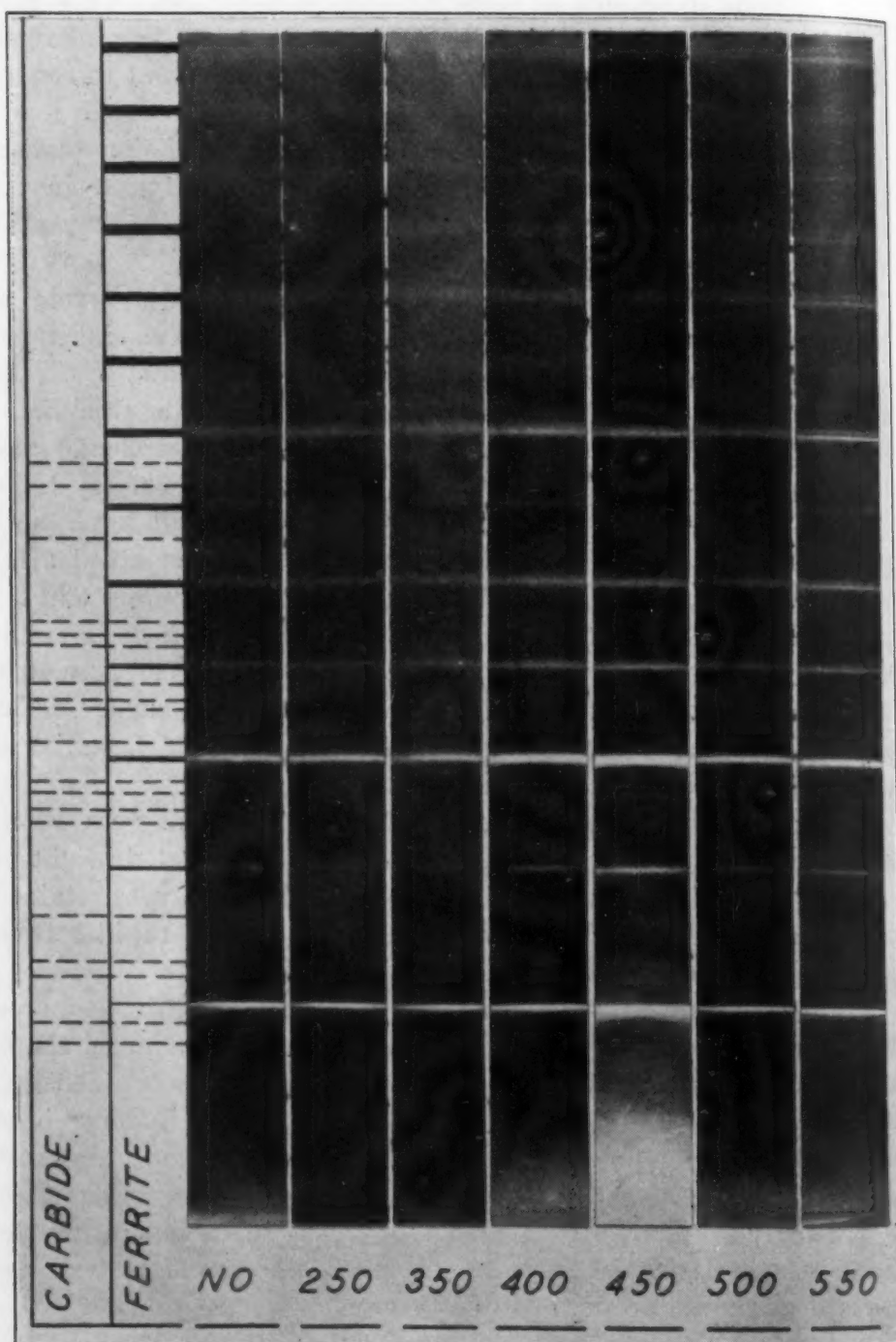
Fig. 5—X-ray Crystallograms Obtained from the Stainless Steel Quenched from 1600 degrees Fahr. (870 degrees Cent.) and Variously Tempered.
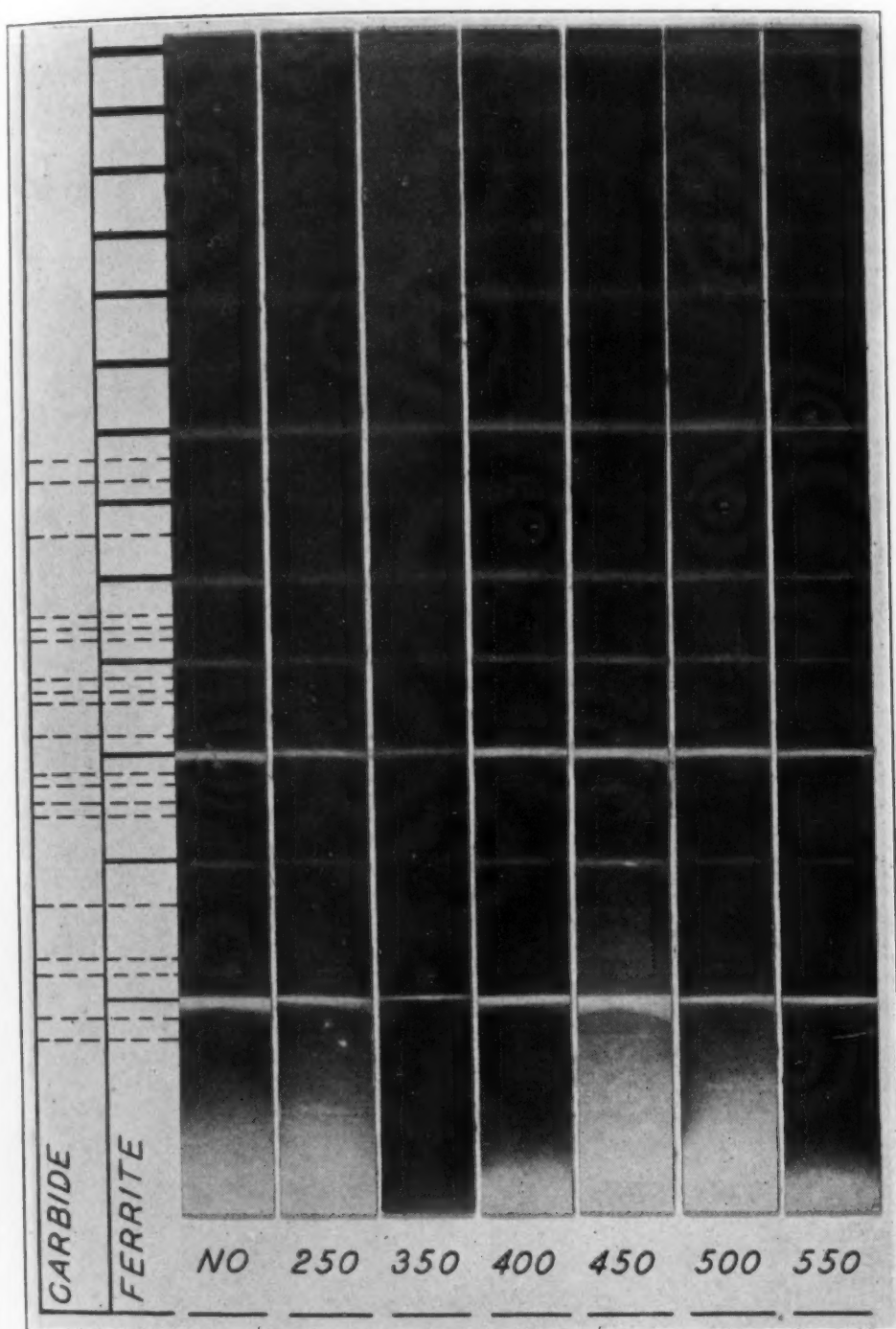
Fig. 6—X-ray Crystallograms Obtained from the Stainless Steel Qeunched from 1700 degrees Fahr. (930 degrees Cent.) and Variously Tempered.

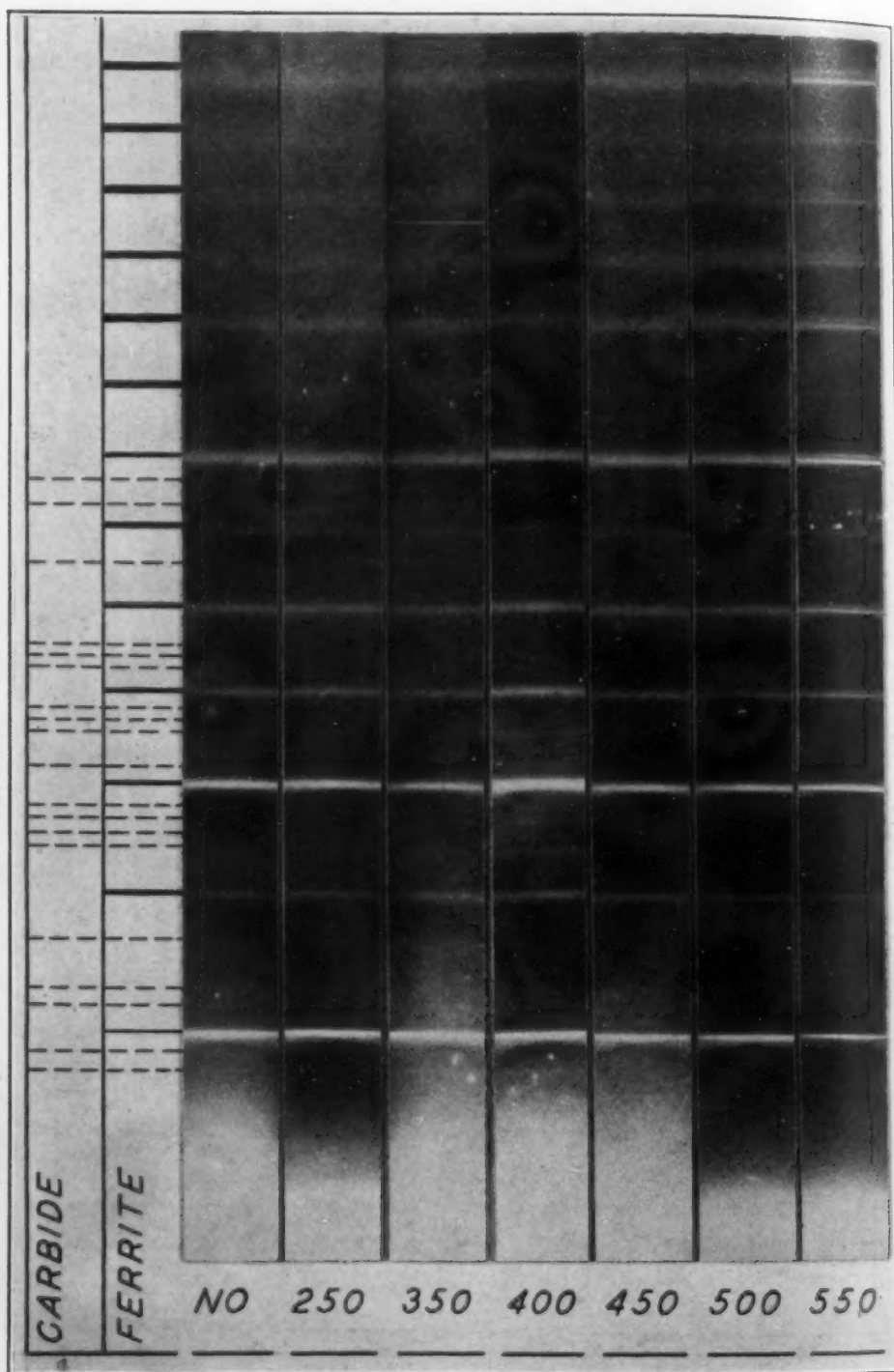Fig. 7—X-ray Crystallograms Obtained from the Stainless Steel Quenched from 1800 degrees Fahr. (985 degrees Cent.) and Variously Tempered.
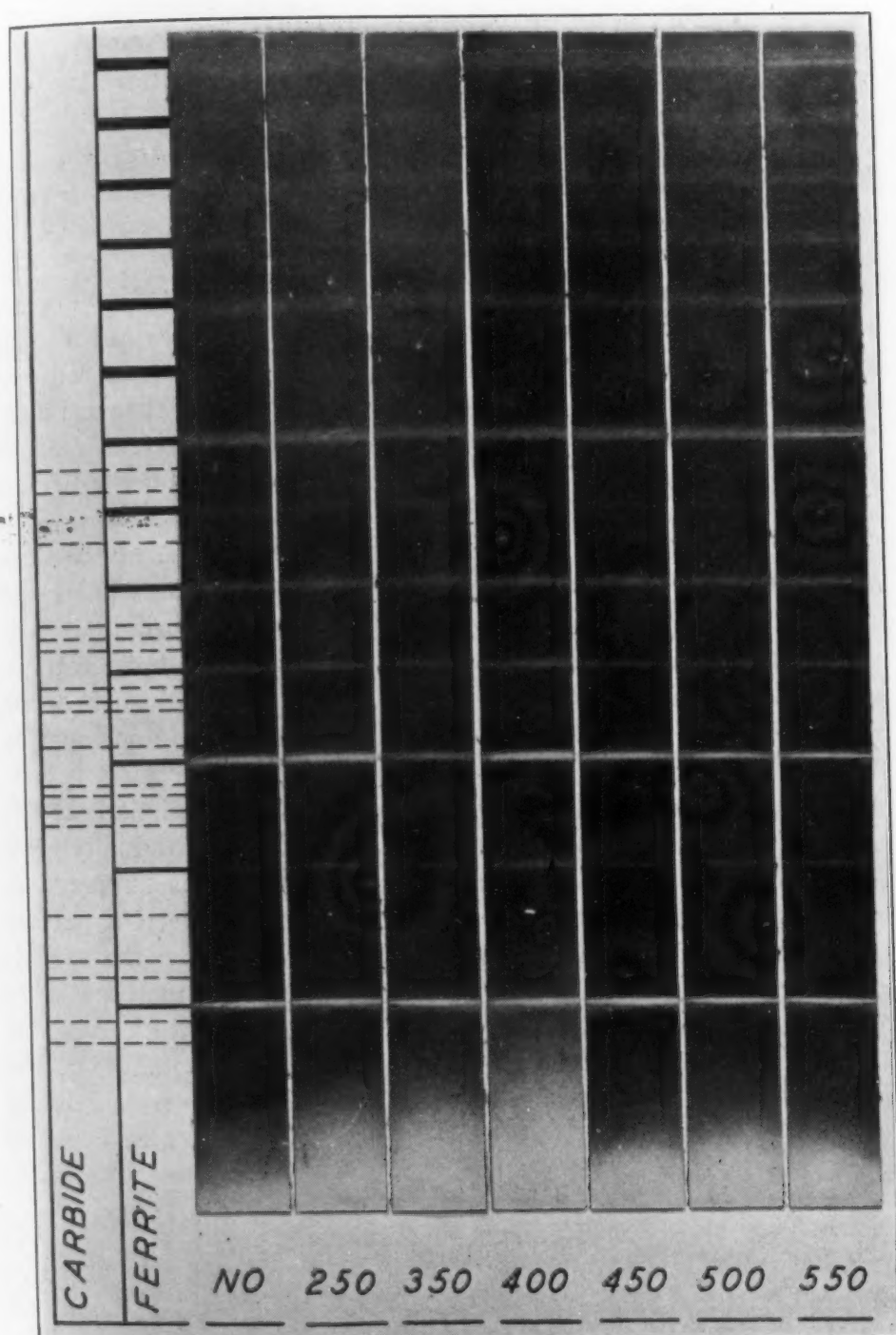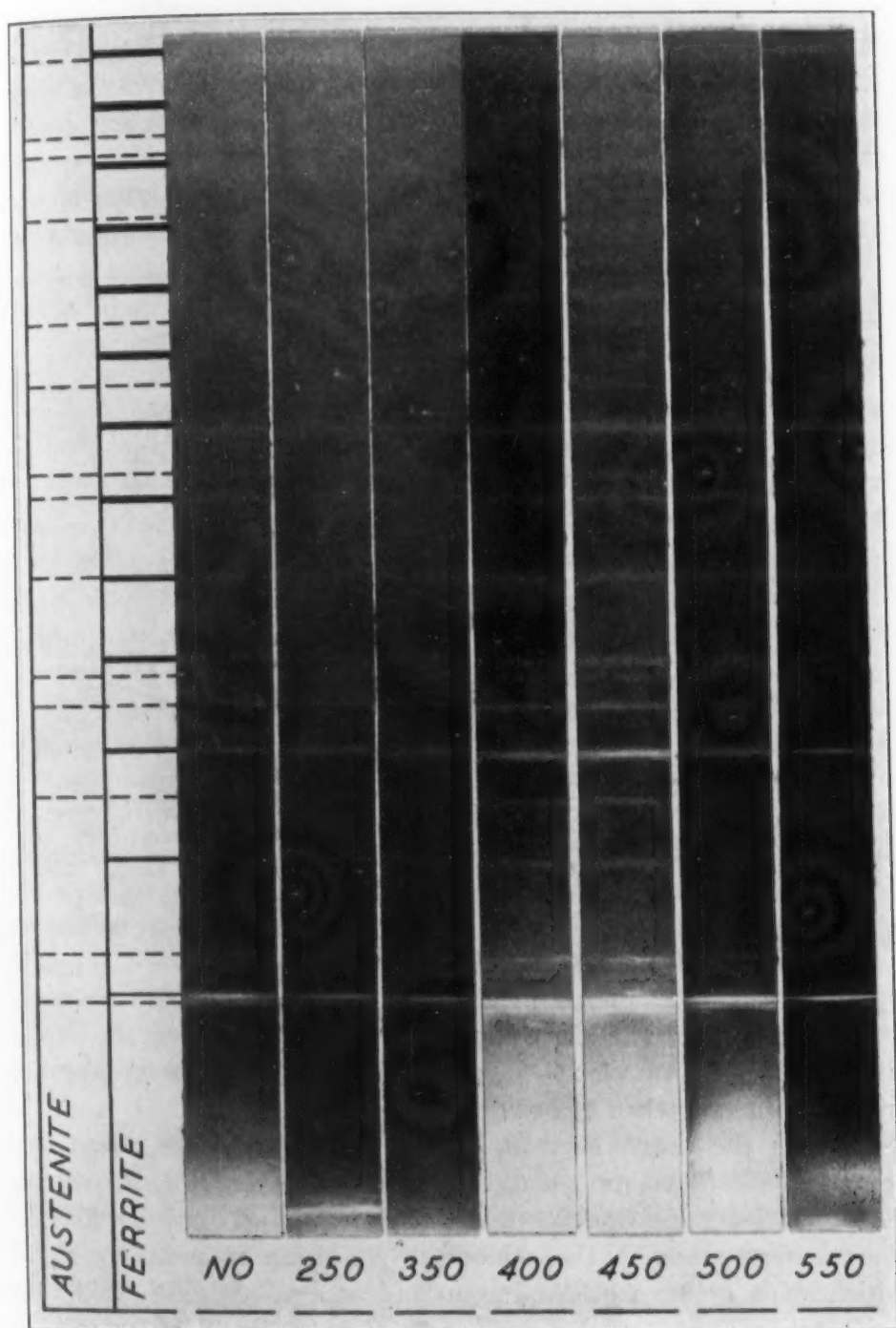
Fig. 8—X-ray Crystallograms Obtained from the Stainless Steel Quenched from 1900 degrees Fahr. (1040 degrees Cent.) and Variously Tempered.

fraction bands. The austenite lines are absent entirely in the pattern of the 1020-degree Fahr. (550 degrees Cent.) temper. Here again it seems that the carbide lines take on a certain sharpness only in the case of tempers above 795 degrees Fahr. (425 degrees Cent.), indicating possibly that even the carbides are held in a stressed condition in martensite, and that the release of such large stresses takes place at about 750 degrees Fahr. (400 degrees Cent.) or 840 degrees Fahr. (450 degrees Cent.).

The patterns obtained from the steel quenched at 2000 degrees Fahr. (1095 degrees Cent.), Fig. 9, reveal the presence of a great deal of austenite retained after the quench. The gamma iron pattern is nearly as strong as the alpha iron pattern and the steel must therefore consist of at least 40 per cent austenite. The amount of austenite does not diminish by tempering treatments of one hour up to 930 degrees Fahr. (500 degrees Cent.) but is destroyed by heating at 1020 degrees Fahr. (550 degrees Cent.) at the same temperature at which the martensite loses its characteristics and becomes well-crystallized alpha iron. Again no carbide is precipitated from either austenite or martensite at these temperatures, at least in sufficiently large particles to contribute to the diffraction of X-rays. The faint carbide pattern revealed in the low tempering treatments persists but is not noticeably intensified.

In all the series of patterns there is a characteristic behavior that is apparent in the original films. The patterns gradually grow stronger and more contrasty as the steel involved is tempered at successively higher temperatures. Of course the ferrite pattern sharpens most definitely and rather abruptly but also the carbide and austenite lines show the same tendency. It is most probably due to the release of the strains in the crystals by the actual disappearance of the balanced stresses within the metal. Or, the actual amount of material in martensite which is far from existing in a perfect space-lattice may be larger than previous evidence has led us to believe.

Nitric Acid Attack

The loss of weight of the variously quenched and tempered specimens is shown in Fig. 10. The acid used was normal HNO_3, a strength which is oxidizing enough to permit the chromium protection to be apparent but yet sufficiently dilute to act as an ordinary

Fig. 9—X-ray Crystallograms Obtained from the Stainless Steel Quenched from 2000 degrees Fahr. (1095 degrees Cent.) and Variously Tempered.

simple acid to some extent. The specimens were gently moved in a
large volume of acid for two hours—a sufficiently long time to
produce measurable loss. After the two hours in the acid the speci-
mens could almost have been arranged by tempers without identifi-
cation due to the appearance of the surface. The lower the quench
and the higher the temper the darker was the surface. The highest
quench and the 705-degree Fahr. (375 degrees Cent.) temper
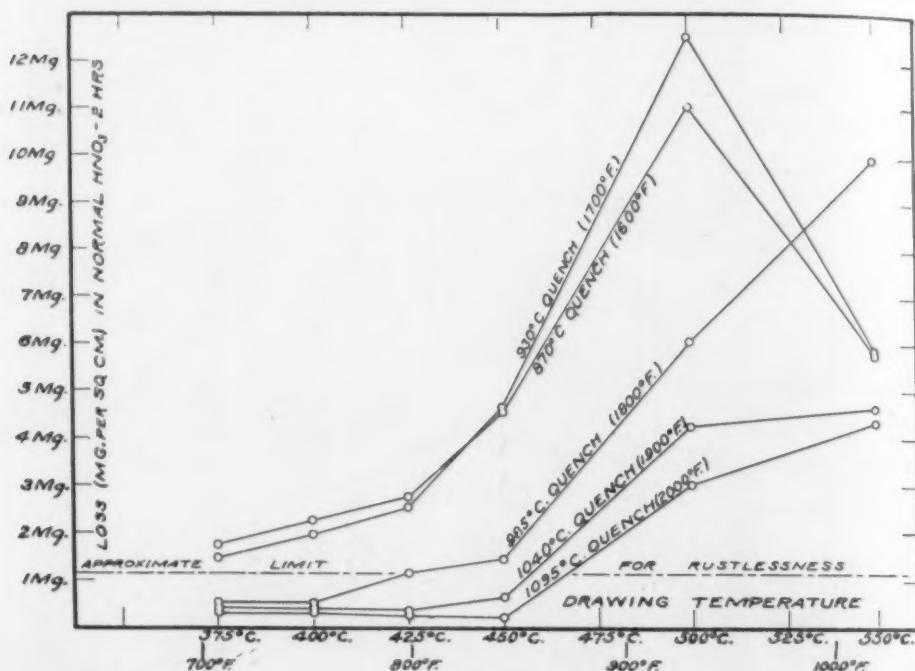
Fig. 10—The Nitric Acid attack of the Stainless Steel as Variously Quenched and
Tempered.

specimen showed almost no change in surface appearance while
the high temper with the 1600-degree Fahr. (870 degrees Cent.)
quench was almost black—reminiscent of the surface appearance
of sorbitic steels when etched.

From the chart, Fig. 10, it will be seen that the lowest two
quenches will develop a material upon tempering to 930 degrees
Fahr. (500 degrees Cent.) which shows maximum attack. This no
doubt corresponds to the osmondite condition in ordinary steels
which show a sharp maximum in acid attack. Higher tempering
temperature removes the steel from the condition of inordinate
attack and it shows merely lack of much chromium protection. In
the case of the steel quenched from 1800 degrees Fahr. (985 degrees
Cent.) the attack increases with tempering temperature uniformly

to the limits of the study indicating that the osmonditic condition is not developed at such tempering temperatures and probably not so definitely even at higher temperatures. The quench at 1800 degrees Fahr. (985 degrees Cent.), however, is quite high enough to produce rustlessness, though it withstands tempering less effectively than higher quenches.

The corrosion resisting properties of the steel as quenched at temperatures above 1830 degrees Fahr. (1000 degrees Cent.) are more or less uniform—the higher temperature quenches withstanding tempering better than the lower. The line drawn upon the chart indicating the limit for rustlessness should be regarded as only an approximation, for each steel seems to be more or less a law unto itself and there have often been isolated behaviors observed by the writer which did not seem to conform to the general trend of properties. However, such occurrences are rare and indicate conditions of experimentation not properly evaluated. At any rate, for a number of alloy series tested in the atmosphere over considerable time the line as drawn is reasonably near the boundary of resistance and attack.

The microscope reveals the presence of a number of carbide particles which never play any part in the metallographic reactions. They are remnants of the original eutectic carbide of the ingot. In the course of reducing the ingot to sheet the eutectic carbide is broken up into fragments sometimes as large as 0.00025 inch average diameter. These separate fragments of inert carbide do not contribute more than an extremely weak carbide pattern of negligible intensity in comparison with the pattern derived from the fine dissolvable carbides which are annealed out.

Summary

It has been shown that in this stainless steel with higher and higher quenching temperatures the corrosion-resistance increases— and the hardness also, up to the point at which a persistent austenite results.

Little change results in the properties of these steels after quenching by tempering up to 750 or 800 degrees Fahr. (400 or 425 degrees Cent.). With higher tempers the corrosion-resistance is injured before marked softening begins. In the case of the high-quenched material distinct secondary hardness is developed begin-

ning at about a 885 degree Fahr. (475 degrees Cent.) temper and reaching a maximum at 930 degrees Fahr. (500 degrees Cent.).

All these properties are chiefly a reflection of carbide behavior. The higher quenches dissolve more and more carbide thereby placing the chromium in a useful form (solid solution) and the tempering action is chiefly one of re-precipitation of carbide which lessens the chromium protection. A considerable amount of submicroscopic carbide precipitation may take place without lessening the hardness since the fine particles act as well to produce hardness and since also the martensites, very high in chromium, are not particularly hard per se.

It may well be that there is a definite dispersion of cathodic carbide particles which encourages maximum acid attack by lessening the path of electrolytic current flow. This thought is offered as an explanation of the sharp maximum of attack for the osmondite condition. At any rate the analogous condition is produced in these steels at 930 degrees Fahr. (500 degrees Cent.) just as it occurs at a much lower temperature in carbon steels. The physical state of the carbide in this condition probably represents the first formation of perfect crystallites with the statistical average size far below microscopic range.

ACKNOWLEDGEMENTS

In gratefully acknowledging the assistance of his associates the author especially extends appreciation to Willis Waring who aided in the researches by skillful operation of the X-ray equipment and to J. R. Vilella for evidence contributed by the microscope. To F. M. Becket under whose authorization the investigation has proceeded, the author is deeply indebted for valuable criticisms.

HARDENING COLD HEADING DIES

By L. S. Cope

Abstract

The author of this paper describes a quenching apparatus which has been successfully used for the quenching of cold header dies. With this apparatus it is possible to quench a die so that the portion around the hole will be hard to withstand wear and the remainder of the die will be soft enough to withstand the shock produced by cold heading. The die is heated to the proper temperature for hardening, it is then placed in the quenching apparatus where water at 80 pounds pressure is allowed to pass through the die. When the outside of the die has cooled to a dull red it is completely submerged until fully cooled. The stream of water continues to pass through the die after it is submerged.

A pair of tongs is also described in this paper by which header hammers may be quenched so that the ends only will be hardened, these are the only parts of the hammer which need be hard.

MATERIAL

FOR many years the steel in almost general use for cold header dies has been a straight carbon steel, the carbon ranging from 0.80 to 1.10 per cent. In some cases, particularly the larger sizes, the 0.80 per cent carbon was used to provide the necessary toughness to withstand the shock, but at the same time sacrificing some of the hardness necessary to withstand wear.

For the smaller sizes of dies the carbon was ofttimes specified as high as 1.10 per cent, where the shock stresses were not severe and where maximum hardness to resist wear, was desired. The small dies likewise have small holes drilled through their centers making it very difficult to effect the proper quench in the hole (the only place where hardness is essential). The higher carbon steel is somewhat of a help in hardening the hole. In other words large dies were low in carbon and small dies high in carbon in

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order to offset the difficulties in quenching. In one case we sacrifice hardness and in the other case we sacrifice toughness. A header die must possess both hardness and toughness. It is a fact, therefore, that the manner in which the quench is made, is equally as important as the steel.

QUENCHING

In Fig. 1 there are shown three methods of quenching a die. At A is shown a die quenched by simple immersion in the bath where it is held by tongs and moved to and fro. This method
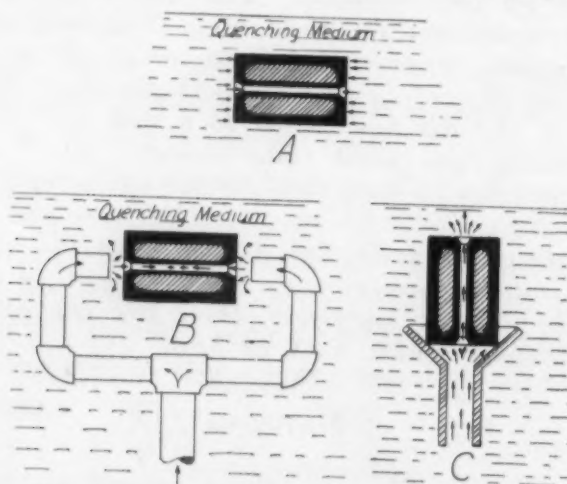
Fig. 1—Diagram Showing Three Methods of Quenching a Die. A Shows Common Method by Immersion. B Shows Die Immersed and Placed Between two Streams of Water. C Shows Die Immersed and Placed Over a Single Stream of Water.

produces a heavy depth of hardness on the outside of the die, and a very shallow shell of hardness around the hole. It is a well known fact that depth of hardness around the hole is just as important as the degree of hardness. If the hardness is merely a shell, the internal pressure set up will crack the shell, expand the hole, and cause it to be useless in a short time.

A die as shown at A is neither tough nor hard and not much life could be expected of it.

At B is shown a common method of making a quench. The die is immersed in the quenching tank and placed between two streams of water directed toward each other. The two streams meet at the center of the die. One of the nozzles had just as well been left off. This method is the same as method A but with variations. It has the same shortcomings as method A.

At C is shown a more modern development. It is the same as method B but with one nozzle left off. Method C provides greater depth of penetration around the hole but still the outside is hard and brittle. It is evident that the method which will produce a proper penetration around the hole and practically no penetration around the outside of the die, will approach the ideal.

IMPROVED QUENCHING APPARATUS

Fig. 2 shows what takes place in a die quenched with a stream of water passing through the hole. The cavity at the lower end of the die is thoroughly quenched but at the upper end of the die the stream passes through without thoroughly quenching the sides
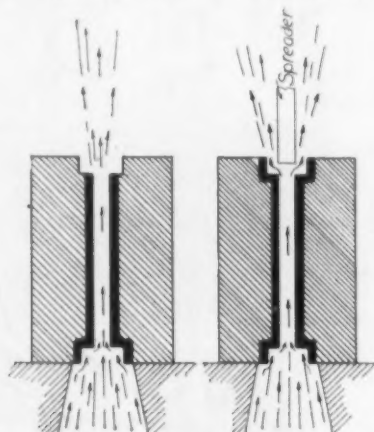
Fig. 2—Diagram Showing Header Dies Quenched by Internal Stream With and Without Spreader. Black Portion Represents Hardened Steel.

of the cavity. We found, however, that by placing a spreader in the upper cavity, thereby making the stream "detour," we were able to harden all parts of the upper cavity. This principle forms the basis for a quenching method and apparatus very successfully used in our plant for hardening double end solid dies. This apparatus is shown in Fig. 3. It consists essentially of an upper shaft G movable endwise and manipulated by hand lever L. The lower end of this shaft terminates in nozzle F. A lower shaft B is hollow for the entrance of the water. Yoke C attached to this shaft is pulled in an upward direction by two cables attached to a spring. The upward motion of shaft B is limited by collar H. Attached to the lower end of the shaft is flexible metal hose A through which the water is introduced. The upper end of shaft B terminated in

nozzle D. Fig. 4 shows to a larger scale the two nozzles. The water enters at the lower end and after passing through the nozzle tips M (which are made in several sizes to accomodate different cavities) it enters the hole in the die, passes around the spreader K and
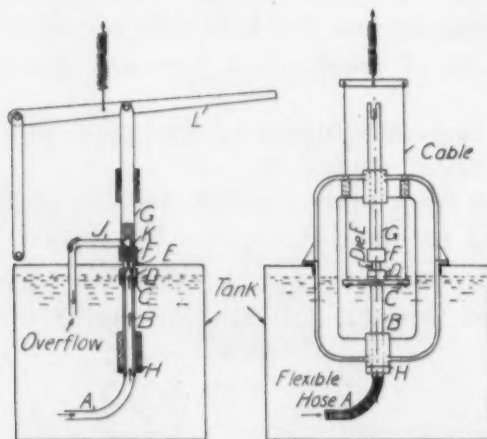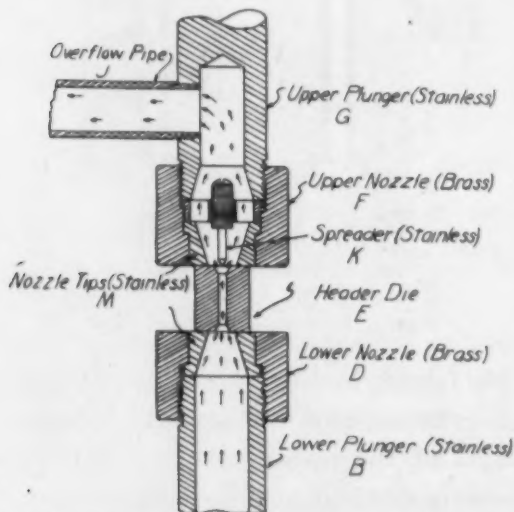
Fig. 3—Diagram Showing Die Quenching Apparatus.

Fig. 4—Diagram Showing Details of the Nozzles.

thence out of the overflow pipe J and back to the quench tank. The spreader K is made in several sizes, some have square ends and others, conical ends to accomodate the various forms of die cavities. The parts of this apparatus likely to become rusty are made of either brass or rustless iron. Fig. 5 shows the lower nozzle and several of the spreaders, and also shows the centering device by which the die is centered over the nozzles.

The method of using this apparatus is as follows: the die, after being heated carefully to the hardening temperature, is removed from the furnace with tongs and placed in the centering device on the lower nozzle. Lever L is next pulled down bringing the upper nozzle F into contact with the die. A quick acting valve is then opened allowing water at 80 pounds pressure to pass through the die and back through overflow J. The quench does not touch the outside of the die but the internal extraction of heat from the hole is so rapid as to cause the temperature of the
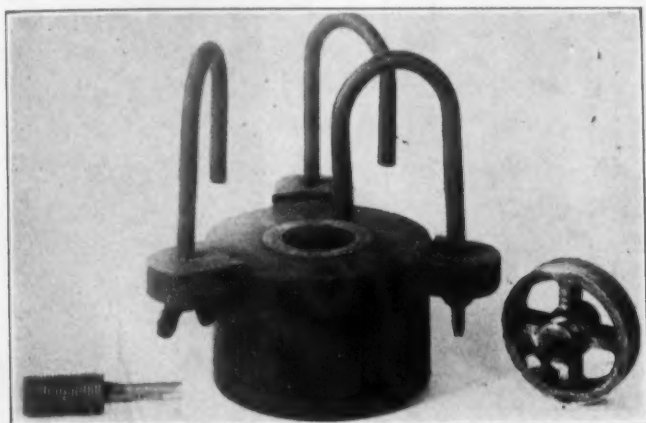
Fig. 5—Photograph Showing the Lower Nozzle and Spreaders also the Centering Device by Which the Die is Centered Over the Nozzles.

die as a whole to drop rapidly, although not sufficiently rapidly to harden the exterior of the die. As soon as the outside of the die has cooled to a dull red, the lever L is further moved downward resulting in submerging the whole die but the stream still continues to pass through the hole. The die is held in this position until it is cold, then lever L is released and the die removed leaving the apparatus in position to quench the next die. The quench requires about 30 seconds in the case of small dies and about 60 seconds for larger dies.

Fig. 6 shows the etched section quenched over a submerged stream. This die was cut in half in the hardened state by means of a 1/16 inch thick grinding wheel and then etched to show the hard and soft areas. Note that the hole and outside of the die are hard, as represented by the light areas. About 50 per cent of the volume of the die is hard and brittle and the greater percentage of this hardness is on the outside of the die where it does no good. Fig.

7 shows a die quenched on the apparatus just described and about 90 per cent of this die is soft ductile metal, the remaining 10 per cent being hard metal and the hardness is applied around the hole where it is needed. It would be conservative to say that we have hardened 25,000 dies on this apparatus and very seldom do we
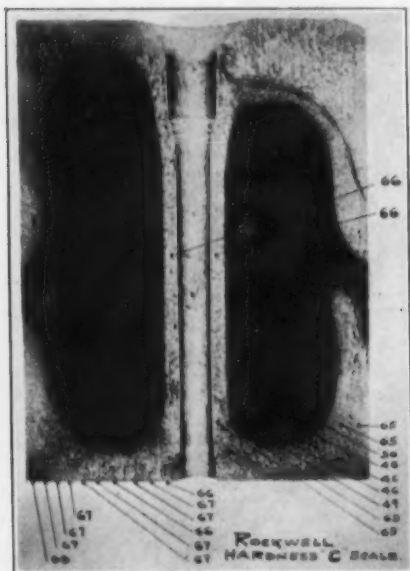

Fig. 6—Photograph Showing the Etched Section of a Die Quenched Over a Submerged Stream.
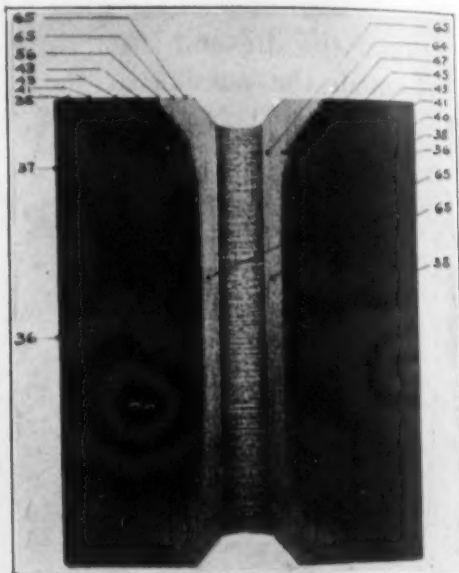
Fig. 7—Photograph Showing the Etched Section of a Die Quenched On the Apparatus Described.

have any complaints of the dies splitting. The holes of the dies simply wear out in the natural way and we feel that with the quench being confined to the holes we have a better chance of getting the hole hard than by any other method.

We also found that when the die was hardened in this manner it was not necessary to resort to a high tempering temperature, therefore practically all solid dies are tempered at 400 degrees Fahr. the temper however is prolonged and usually lasts 12 hours. The day's production of hardened dies is placed in an automatically controlled electric furnace and held at the given temperature until the morning.

It was stated that dies seldom cracked but an exception must be made in the case of dies which are torn in the machining or broaching operation, or dies with odd shaped cavities having sharp corners. These dies, however, constitute a very small minority, as about 90 per cent of the dies made have holes wherein the ma-

chining operation is the product of revolution (where the hole or cavity is drilled out).

ANALYSIS OF HEADER DIE STEEL

As a result of hardening dies in this manner, we have been able to standardize on one grade and analysis of steel, the carbon
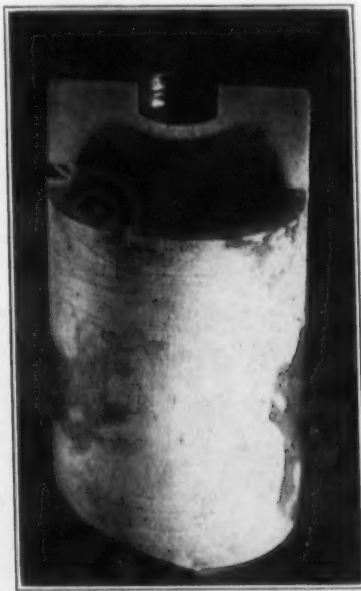

Fig. 8—Photograph of a Hammer Which Broke in Service.

Fig. 9—Photograph of a Cross Section of the Hammer shown in Fig. 8 After Etching in Aqua Regia.

content being 0.95 to 1.00 per cent. We make no distinction between small and large dies, using the same analysis for both.

Hole Grinding—We have observed that dies quenched as described above, do not warp as much as when quenched by other methods. Cold headermen have always had more or less trouble with the holes of the dies, enlarging at both ends of the die, and shrinking in the center of the die. To use the headermen's "jargon" they go "bell-mouthed." This enlargement or shrinkage of the hole may be as small as 0.002 inches but the tolerance on the product to be cold-headed is frequently only 0.002 inches, therefore, shrinkage even in small quantities is a detriment. The holes also may be rough from the drilling or reaming operation, or they may be slightly scaled or even decarburized after the die is hardened.

A tool used by the headerman for polishing the holes in his dies consists of a piece of drill rod with a strip of emery cloth spirally wrapped around it. This device is revolved in a speed lathe, and the die is worked back and forth by hand over it. This

Fig. 10—Photograph of a Pair of Tongs Devised for Quenching Hammers Which are to be Hard Only on the Ends.

results in somewhat "trueing" up the hole, at least enough to get by. We are at present grinding these holes on an internal grinding machine, using a special air driven high speed spindle. Using grinding wheels mounted on steel mandrels we are able to grind holes as small as $\frac{1}{8}$ inch diameter. The holes are thus ground true to size within 0.0003 inch and not only have we greatly improved the die life, but we find we can grind these dies in less time than the headerman with his primitive emery cloth lap.

Header Hammers—The header hammer (or header tool which strikes the blow) sometimes is troublesome, especially where the hammer is recessed to form some particular head on a bolt or screw. In Fig. 8 is shown a hammer which broke in service. Note the type of fracture. In Fig. 9 is shown this same die, the cross sec-

tion of which has been etched in aqua regia. In hardening this hammer, it was simply heated to the proper temperature and submerged in the quench. The entire surface of the hammer is file-hard to a depth of about 3/16 inches.

Bearing in mind that the only parts of the hammer which need be hard, are the two ends, we prepared to harden the ends only. We did this by using a pair of tongs, such as are shown in
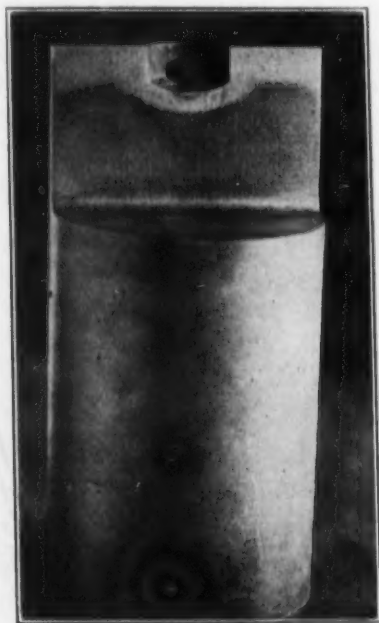

Fig. 11—Photograph of an Etched
Section of a Hammer Quenched Using
the Tongs Shown in Fig. 10.

Fig. 10. This is an ordinary pair of tongs except that the jaws are made to fit the outside of the hammer snugly so that when the hammer is quenched, only the ends are exposed to the quenching medium. In this way a tool such as is shown in Fig. 11, is produced. Note that the end only is hardened. In this way we practically eliminated all breakage. Thus we have described two methods of quenching tools to locally harden the parts required to be hard, and to leave the remaining part of the tool soft and ductile for toughness. A blacksmith would never think of hardening a chisel all over. He hardens the cutting edge only and leaves the rest of the chisel soft to stand up under the hammer blows. It is the writer's belief that we could eliminate the breakage of many

tools if we would harden them like the blacksmith hardens his chisels.

Conclusion

I have described several methods we use in treating steel, in order that the maximum of efficiency may be obtained from the tool. The quality of the steel and the method of heat treating play an important part in the performance of a tool. If the steel is defective or of a grade not suited to the purpose, the finished tool made therefrom may be useless. The cost of labor used in making the tool may be many times the cost of the actual steel used. Or, on the other hand, a perfect piece of steel may be used and the tool ruined by carelessness or lack of knowledge on the part of the heat treater. But there are other causes which contribute to premature tool failure over which the heat treater or the steel supplier have no control.

SOME GENERAL THOUGHTS ON FUSION WELDING

By S. W. Miller

Abstract

A comparison is made between different methods of welding, showing the need in all of them for protection of the metal from oxidation, or removal of oxides formed by the heat, if the best results are to be obtained.

An explanation is given of the action of fluxes, and of the advantages of making rods for fusion welding of the proper chemical composition, so that the resultant welds will be free from oxides. The advantages of higher strength and ductility obtained by the use of such rods, are pointed out, and the necessity of scientific investigation is explained. It is urged that this kind of study be used in all cases, so that the inherent advantages of fusion welding may be as fully realized as possible.

THE term "fusion welding" is properly applied to any process by which two pieces of metal are joined, either by melting them together, or by applying additional melted metal between their melted surfaces. It is different from brazing or soldering in that in the latter cases only the added metal is fused. It differs from forge or hammer welding in that in these processes the metals joined are not fused, but brought only to the temperature that allows them to be pressed or hammered together so that a solid union may be made. In all cases in which these processes are properly carried out, the union is molecular. The difficulty with any of them is to avoid the inclusion of oxides or other dirt between the pieces or in the weld metal.

Fluxes have been used for years with soldering and brazing to remove these oxides, or to prevent their formation, and their use has accomplished the desired results. Also the use of borax or sand by the blacksmith in his forge welding is an old practice.

There is another method that will answer the purpose in some

cases. It is to put into the materials to be joined the elements necessary to do the fluxing. Comparatively high phosphorus in pipe skelp is one instance, and the use of low carbon steel for forge welding is somewhat analogous.

In fusion welding the need of fluxes is great in some cases, as for example with brass or bronze, or cast iron. They are not used so much in the case of steel with either gas or arc welding, although many coatings and similar methods have been devised, especially for arc welding.

It is probably true that where it is possible to incorporate suitable elements in the rod itself, better welds can be made than where the deoxidizing or slag-forming elements are in the form of a coating or covering. Such elements as manganese and silicon, that oxidize preferentially carbon and iron, not only greatly decrease the oxidation of these latter elements, but add to the strength of the weld when present in proper amounts. Their action is the natural result of oxidation, their oxides combining with the iron oxide formed to make a thin, rather viscous slag, that does not prevent the transfer of heat to the metal, but prevents the access of air to it. Not only is the weld metal protected, but the fluidity of the slag allows it to run ahead of the weld metal onto the base metal, cleaning it and allowing of rapid and sound welding.

The following analyses show what occurs in gas welding:

	Rod Per Cent	Weld Per Cent
Carbon	0.20	0.17
Manganese	0.80	0.50
Silicon	0.55	0.30

With the usual welding rod, that contains about 0.06 per cent carbon, 0.15 per cent manganese, and practically no silicon, it is evident that the weld must be more or less oxidized, and this is found to be true. Also its strength must be less than that given by a rod of proper composition. This has likewise been found to be the case. A great additional advantage of the better rods is that in all cases they make the welding easier, so that after a few hours' practice, the welds made by the average welder are stronger and better in every way, the strength increasing from 15 to 25 per cent, and the general quality of the weld being much better.

The author has selected one rod and one process as an illustration, but desires to bring out the point that careful metallurgical

study is needed with all processes if we expect to improve the quality of welding and broaden its application.

Fusion welding is a very attractive process, because of its cheapness, and the wide variety and ease of its application. It results in a joint that in most cases is unequalled for strength, tightness, reliability and safety. In other cases the inherent conditions are such that it is impossible to expect the best results, and in a few instances the results are quite unsatisfactory. But it is no different in this respect from other methods of joining, no one of which is suitable for all cases, and it has such marked advantages where it is applicable, that it is very rapidly replacing older methods in many instances, as well as making new fields for itself.

The characteristics of a fusion welded piece depend on the process employed, and on the materials used, both base metals and welding rod, so it is not possible to state them generally. It may be said, however, that weld metal naturally cannot equal forged and heat treated alloy steel in physical properties. As a corollary of this, fusion welding should not be used where such results are required. Good weld metal, made by commercial welders, may have 65,000 pounds per square inch ultimate strength, 48,000 pounds per square inch yield point, 25 per cent elongation in 2 inches, and 40 per cent reduction of area.

These figures apply to the weld metal itself when it is of the proper composition, and are for gas welding. It may be well to point out that the yield point of such weld metal, and also of some others, is considerably higher than that of ordinary steel plate. Therefore, in an ordinary welded tensile test piece there is but little elongation across the weld.

Two recent papers, one by A. B. Kinzel, read before the A. S. S. T. at the last meeting in Detroit, and the other by W. B. Miller, read at the same time before the American Welding Society, show that consistent and accurate results as to the ductility of weld metal can be obtained by a suitable bend test.

This difference in yield point, however, is of no importance in practice, because welded structures are not stressed beyond the yield point, and the coefficient of elasticity is the same for both weld and base metals.

To attain these values in practice, proper procedure must be followed, beginning with the design, and including proper selection

of materials, correct training of the welders, inspection and supervision. Successful fusion welding is not a haphazard process. Consistently good results cannot be obtained in any work by hit and miss methods. There is, therefore, every reason for applying the same careful study to welding that we naturally apply to other processes.

Fusion welding, like anything else, has its limitations, but scientific study is gradually removing them. As an illustration, the case of welding copper-tin alloys may be cited. One common alloy is 90 per cent copper and 10 per cent tin. In castings that cool fairly rapidly, such as those of moderate size, the delta constituent is present in considerable amounts, although copper will dissolve more than 10 per cent of tin when the alloy is in equilibrium, and then only the alpha solution is present.

The delta constituent has a lower melting point than the alpha constituent, so that when welding a 90 copper 10 tin bronze containing the delta constituent, it boils out on the surface before the alpha constituent is melted, and is absorbed by the melted metal from the welding rod. There are two results; first, a heavy concentration of tin next to the weld line, making the metal at that point brittle; and second, the formation of cavities in the base metal a short distance from the weld line, due to the removal of the delta constituent, through which cavities the rupture always occurs under test. Apparently it is not possible to weld such material successfully.

But the equilibrium diagram shows that above 930 degrees Fahr. (500 degrees Cent.) the alpha plus delta structure changes to alpha plus beta, and that this can contain nearly 30 per cent of tin at about 980 degrees Fahr. (525 degrees Cent.). So if the piece is heated to 980 to 1020 degrees Fahr. (525 to 550 degrees Cent.) for a long enough time for the change to occur, the welding can proceed without danger from either of the causes mentioned. The rate of cooling should be about that of the original casting.

Even so common a job as welding cast iron, was in the early days of welding, thought to be impossible. The welds were porous, dirty, hard, brittle, and unmachinable. An excess of silicon in the welding rod, and the use of suitable fluxes, were mostly responsible for the good results now obtainable.

It appears to the author that the members of the American

Society for Steel Treating are peculiarly qualified by their technical knowledge to look at welding problems with clear vision, especially where steel is involved, and I would urge you to apply this knowledge to the study of how you may use fusion welding to advantage.

There are many sources of information on which to draw, and good commercial organizations that sell welding apparatus and supplies are also selling welding—good welding—to their customers through their service departments.

You naturally ask, "Where can I use fusion welding?" I think the best answer I can make is that I cannot make out a list of applications, but that each of you should study his own problems in the light of available information as to the characteristics of weld metals, but not forgetting that things that were formerly thought impossible are now being done as a matter of course, and that careful thought and research will show that the possibilities are numerous and that the successful applications will be many.

Cost of Welding

Of course, cost is always an important consideration. But cost figures should come from the accounting department and not from the shop, if accuracy is desired, as there are elements in the total cost that the shop cannot know of. Different companies have different methods of accounting, but they all give results that are suitable for comparisons. The cost of welding is not the only consideration, as welding may reduce other costs enough to pay the welding expense. All these matters, upon which real cost depends, are proper subjects for careful consideration of the management, before any decision is made. Low cost is often deceptive, as a cheap process may not give good results, while a higher welding cost may be fully justified by the superior product obtained.

I speak of all this because welding cost figures are often given with little regard to the facts. For instance, I once received a letter from a manufacturer of a welding machine, in which it was stated that his machine could be operated for ten cents per hour, which evidently would not cover the cost of the current. Such statements will not bear analysis, and should not be accepted at their face value.

DISCUSSION

Written Discussion: By E. E. Thum, The Iron Age, New York City.

A question may be asked as to whether oxyacetylene welded joints have good fatigue properties. I wish to point out that the fatigue test and the fatigue test pieces, as used by leading American investigators, are not suitable for investigating the properties of a heterogeneous joint like a welded joint. A large amount of work has been done by the American Welding Society and others to develop proper methods of testing joints in tension and otherwise.

A weld changed from uneffected metal some distance on either side of the joint through various tempered, annealed, recrystallized and cast structures as the center of the joint was reached and the chemical composition of the added material is likely to be quite different from the chemical composition of the metal joined. For engineering purposes, it is obvious that this complex aggregate of structures should be tested as a unit, for it is apparent that it would be perfectly possible to place superfine material in a joint and yet ruin the zone immediately alongside. A test piece cut from the middle of the weld in such instances would give a wholly erroneous view of the strength and efficiency of the section.

A NOTE

A NOTE ON THE HARDNESS AND IMPACT RESISTANCE OF CHROMIUM-NICKEL STEEL

By B. F. Shepherd

Abstract

This paper gives results of Izod impact, hardness and tensile tests of chromium-nickel steel of the S. A. E. 3250 type with varying nickel and carbon content. Higher carbon reduces resistance to impact without production of increased hardness. Tempering to 300 degrees Fahr. increases impact resistance without materially affecting the hardness but best use of this type of steel is with 550-degree Fahr. temper. The service application and reason for this is briefly discussed.

M ANY service conditions call for parts which must have high hardness and be capable of standing considerable shock, necessitating low residual hardening stresses. All steels, in general, as hardened, have low resistance to shock due to their "hard" condition and reduction of available strength resulting from the hardening stresses. The latter vary greatly with the type of steel and shape of section. Tempering reduces them, but also, in general, reduces the hardness materially when over 350 to 400 degrees Fahr. They are increased by the drastic quenches necessary to obtain hardness in water hardening steels.

Oil hardening chromium-nickel steel of the S. A. E. 3250 type is very useful for service of this character. The reported use of a higher carbon range; 0.62 to 0.67 per cent carbon, to obtain higher hardness with little loss in toughness led to the following comparison of the hardness, tensile and impact values obtainable with steel of this type. The bars were 1-inch round, annealed, and of the analysis given in Table I.

Tensile and Izod bars were rough-ground to within 0.010-0.015 inch of the finish size; the Izod bars being unnotched. After hardening, the bars were ground to shape, the underside of the head of the tensile bars being "squared" with the axis. The Izod bars were

The
results
The fail

Table I
Chemical Compositions

Bar Number	Lab* Number	C	Mn	P	S	Si	Ni	Cr
1	1	0.50	0.40				2.33	0.97
1	2	0.50	0.40	0.008	0.013	0.26	2.35	0.95
2	1	0.51	0.51				1.75	0.94
2	2	0.51	0.51	0.011	0.013	0.22	1.78	0.97
3	1	0.63	0.46				1.81	0.99
3	2	0.62	0.49				1.90	1.01

*Analysis—Lab No. 2.   Courtesy Howard J. Stagg.

notched by grinding with a 45-degree notch, 1/64 inch deep, 0.010 inch radius at the bottom. This work was done very carefully so as to maintain as uniform a condition and smooth a finish as possible. The uniformity of the individual tests which is a measure of this condition is gratifying. Preliminary experiments to determine effect of depth of notch are given in Table II. The bottom portion of each Izod bar was also tested unnotched.

Six tensile bars and three Izod bars from each type of steel were quenched in oil from lead at 1500 degrees Fahr., an equal quantity from lead at 1450 degrees Fahr. Tempering was done in an electric furnace, 2 hours, 40 minutes at 300 degrees Fahr. and 2 hours, 30 minutes at 550 degrees Fahr.

Izod test pieces were set with a gage. The tensile tests were made in a hydraulic 60,000-pound tensile machine, with "self aligning" ball grips and extensometer.

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Table II
Effect of Depth of Notch upon Izod Impact Tests
0.450 diameter bar, 45-degree notch, 0.010-inch radius at bottom.
All bars quenched from lead at 1450 degrees Fahr., tempered at
550 degrees Fahr.

Depth Notch, Inch	Bar No. 1 (high 2.33 Ni.)		Unnotched	Bar No. 2 (Low 1.75 Ni)		Unnotched	Bar No. 3 (high 0.64 C.)		Unnotched
		Average			Average			Average	
0.005	70-80-58	69.3	N B.*	65-61-66	64.	N. B.*			
1/64	**29-28-30	29.	N. B.	22-21-21	21.3	N. B.	17-16-16	16.3	N. B.
1/32	24-24-24	24.	N. B.	20-22-20	21.7	N. B.			
1/16	20-18-18	18.7	N. B.	16-16-14	14.7	N. B.			

*N. B. indicates not broken.
**From Table III.

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The acceptable tests which broke in the acting length gave results closely approximating those published for this material. The failures at low unit stresses of the other bars show that ex-

Photomacrograph of Tensile Test Specimen Showing Fracture in Gage Length Due to Non-axial Loading.

tremely special apparatus is necessary to get proper testing conditions for determination of tensile strength of steels having low deformability. Failures of "hard" parts in service are due in a large

Table III
Effect of Quenching and Tempering Temperature upon Izod Tests
0.450 diameter bar, 45-degree notch, 1/64-inch deep, 0.010-inch radius at bottom

	Bar No. 1 (high 2.33% Ni.)			Bar No. 2 (low 1.75% Ni.)			Bar No. 3 (high 0.64% C.)		
		Average	Unnotched		Average	Unnotched		Average	Unnotched
Quenched from 1450° F.									
Not tempered	12-16-18	15.3	N. B.	10-10-10	10	N. B.	7- 8- 7½	7½	16
Tempered 300	31-28-28	29	N. B.	18-14-20	17.3	N. B.	13-14-11	12.7	116
Tempered 550	29-28-30	29	N. B.	22-21-21	21.3	N. B.	17-16-16	16.3	114
Quenched from 1500° F.									
Not tempered	13-13-17	14.3	N. B.	7- 7- 8	7.3	N. B.	8- 8-10	8.7	47
Tempered 300	29-26-30	28.3	N. B.	20-23-19	20.7	N. B.	8- 5- 6	6.3	N. B.
Tempered 550	27-26-26	26.3	N. B.	16-16-16	16	N. B.	16-17-15	16	N. B.

measure to the same cause i. e., local stresses over the available strength. The unyielding character of the steel prevents slight local distortion and uniform distribution of the load. The high-

Table IV
Effect of Quenching and Tempering Temperatures upon Rockwell Hardness

	Bar No. 1 (high 2.33% Ni.)		Bar No. 2 (low 1.75% Ni.)		Bar No. 3 (high 0.64% C.)	
	Izod	Tensile	Izod	Tensile	Izod	Tensile
Quenched from 1450 degrees F.						
Not tempered	57	56	58	57	59.5	58
Tempered 300 deg. F.	56	55½	55½	56	57.8	57
Tempered 550 deg. F.	49	51	50	50	50½	50
Quenched from 1500 degrees F.						
Not tempered	56	57	58	57½	59	59
Tempered 300 deg. F.	56	55½	57	56	59	58
Tempered 550 deg. F.	50	50	51	49½	52	52

All figures averages of at least five tests.

est elongation and reduction of area obtainable for the permissible hardness of any part provides a "safety valve" to protect it against failure due to sudden overloads in service.

These tests seem to indicate that there is no material increase in hardness obtainable by use of a higher carbon content in this type of

Table V
Effect of Quenching and Tempering Temperature upon Tensile Properties

	Bar No.	Proportional Limit, Lbs. Per Sq. In.	Tensile Strength Lbs. Sq. In.	Elongation Per Cent in 2 Inches	Red. Per Cent	Fracture
Quench 1450° F. Not tempered	1		*155,000			Broke under head
	2		*136,000			Broke under head
	3		* 66,750			Broke under head
Quench 1450° F. Tempered 300° F.	1		*209,500			Broke under head
	2		*105,000			Broke under head
	3		*107,000			Broke under head
Quench 1450° F. Tempered 550° F.	1	233,750	264,500	8.0	22.5	¾ cupped
	2	over 200,000	275,000	7.5	24.0	Full cupped
	3	228,750	273,500	6.0	17.0	½ cupped
Quench 1500° F. Not tempered	1		*240,000			Broke under head
	2		*139,500			Broke under head
	3		*146,000			Broke under head
Quench 1500° F. Tempered 300° F.	1		*175,000			Non-axial loading†
	2		*248,000			Broke under head
	3		*177,000			Broke under head
Quench 1500° F. Tempered 550° F.	1	218,750	266,000	8.5	30.5	½ cupped
	2	230,000	271,500	9.5	31.5	¾ cupped
	3		*195,500			Broke under head

*Breaking load calculated in pounds per square inch on acting length for comparison purposes.

†See photo, page 69.

steel but a serious decrease in impact resistance in both notched and unnotched Izod bars. With equal carbon and chromium contents, the higher nickel content gives better impact resistance with no material change in hardness. A variation in quenching temperature of 50 degrees Fahr. produces no material difference in hardness, either as quenched or tempered. The "as quenched" bars have low resistance to impact. Tempering to 300 degrees Fahr. produces very little reduction in hardness but increases the impact resistance approximately 100 per cent and as much as a 550-degree Fahr. temper. The higher hardness of this 300-degree Fahr. temper is reflected in the "non-adjustability" under slow or tensile loading where all breaks occurred outside the gage length.

Conclusion

This steel should be used in the standard analysis range. A tempering temperature of 550 degrees Fahr. should be used to obtain as great resistance as possible to eccentric loading conditions where hardness is not extremely important. In such cases, while slight increase may be had by use of the 300-degree Fahr. temper, it would be better to use another type of steel. In no case should this material be used without tempering.

THE AUTOMOBILE DRIVE SHAFT

By Raymond L. Rolf

Abstract

This paper briefly outlines in a non-technical manner the manufacture of the automobile drive shaft, touching upon such features as design, forging, machining, testing, physical properties and materials used. It shows the advantage of using a molybdenum steel to obtain easy machinability at high Brinell hardnesses, thus enabling shafts to be completely machined in the heat treated state.

DRIVE shafts may be classified as either full-floating or fixed-hub design. In the full-floating construction, Fig. 1, the inner end of the shaft is engaged with the differential side gears by either a square or splines. The outer end is attached to the wheel either through a flange formed integrally with the shaft, or secured to the shaft by means of a square, splines, or keys. The wheel hub is supported on the housing by a pair of bearings spaced at such a distance as practice has found best.

Under the fixed hub design there are two general types, the semifloating and the three-quarter floating type. A semifloating design is illustrated in Fig. 2. This construction has the bearings mounted on the drive shaft and on the inside of an extension on the housing. Fig. 3 illustrates a three-quarter floating axle. The wheel bearings are mounted on the axle housing instead of on the drive shaft. This brings the strain due to the weight of the car on the housings.

If the car always moved straight ahead over smooth roadways, rear axle design would be simple. To calculate for downward pressure and load and the torque required for turning the wheels would only require simple engineering, but there are side pressures and skidding forces that must be considered. To get a clearer understanding of these forces and the essential differences in the various types of rear axles, let us overlook the turning force, which is the same on all designs and consider only the combined action of the skidding force and downward pressure.

The author, R. L. Rolf, a member of the Society, is metallurgical engineer, Columbia Axle Company, Cleveland.

When a car is not in motion it has a downward pressure on the spring pads due to the weight of the car and passenger load. There is a reaction or equal force pressing up at the ground. These equal forces are termed static load and tend to bend the axle. The skidding force acts at right angles to the static load or in the side direction and tends to cause the axle to bend upward or downward depending upon the direction of stress. Thus with both static and skidding forces tending toward bending the assembly we observe that it is the combination of the two that determines the maximum stresses that have to be calculated when designing a rear axle.

In the full floating type of axle (Fig. 1) the housing carries the bending stresses due to the static and skidding forces, while the drive shafts "float" within the housing and only transmit the power from the differential to the wheels.

In the semifloating construction (Fig. 2) the drive shafts rotate freely within the housing, but their outer ends are attached to the wheel hubs, and they must carry both torque and bending loads.

In the three-quarter floating construction the housing extends into the wheel hubs on which the bearings are mounted. The flange on the end of the shaft is firmly secured to the wheel so that practically all the bending stress and torque loads are distributed to the shafts.

Several types of shafts are illustrated by Figs. 4, 5, 6. It will be noted from these illustrations that the floating axle is practically uniform in section while the semifloating type is a tapered design, being made heaviest where the stresses are the greatest, which is under the main outer bearings and tapering gradually toward the differential, to withstand the bending stresses. When considering the torsional loads on the drive shafts it should not be forgotten that the torsional stress of the engine is multiplied many times by the low speed gears in the transmission and again by the driving gears in the differential.

The principal stress on a shaft is torque, so it should be tested in torsion. This is accomplished by means of a torsion testing machine by pressing the drive flange on the shaft and using special grips machined to fit over the flange so as to distribute the load to the shaft through the wheel bolts. The distortion is measured by means of a specially designed twist meter graduated in fractions of

a turn. The load is applied in increments of 2000 pounds until destruction and the readings plotted. The elastic limit is determined from the plotted curves. Fig. 7 shows a comparison of results
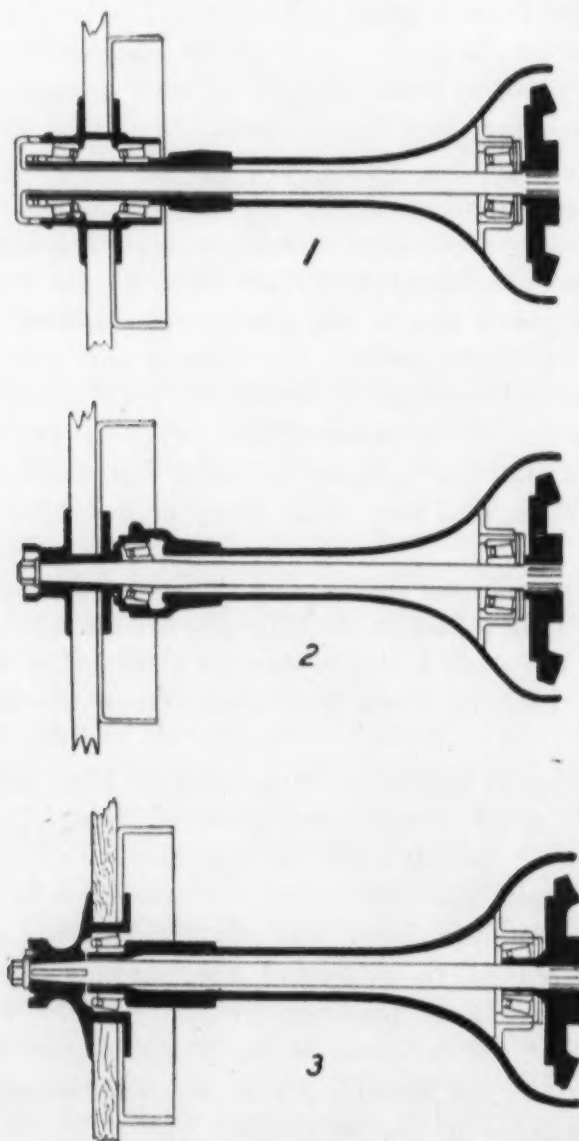

Fig. 1—Diagram Showing Construction of the Full Floating Type of Axle. Fig. 2—Diagram Showing Construction of the Semifloating Type of Axle. Fig. 3—Diagram Showing Construction of the Three-Quarter Floating Type of Axle.

on three different steels heat treated to the same Brinell hardness number.

It is not always convenient to test a shaft in torsion. When

this is found impossible then a standard tensile test may suffice. The test specimen should be turned from the differential end of a heat treated shaft, taking the sample one-half way between the outside and center. The results obtained on several shafts of equal cross section, but of various compositions and heat treated to a Brinell hardness of 364 to 418 are tabulated in Table II.

To meet the tremendous demands of service, a careful study of a multiplicity of analyses, heat treatments and tests are required.
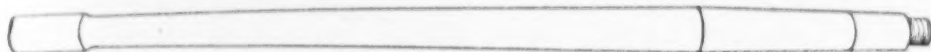
Fig. 4—Semifloating Drive Shaft.
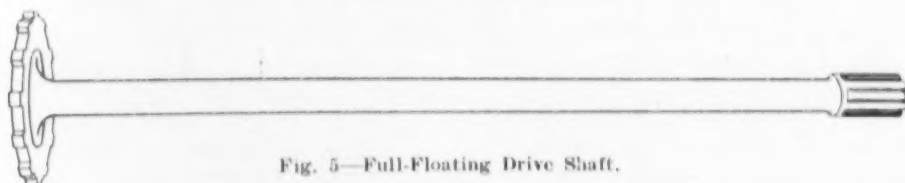
Fig. 5—Full-Floating Drive Shaft.
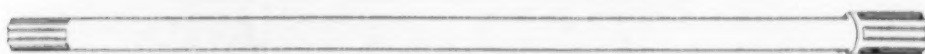
Fig. 6—Full-Floating Drive Shaft.

There are various types of alloy steels on the market, all of which bear close relation in their physical properties and will yield the necessary strength and factor of safety in the finished product.

This wide range of alloy steels permits the consumer to have at his command a variety of materials all of which are satisfactory as far as static or dynamic properties are concerned, therefore, his ultimate choice must be influenced by the performance of the material in various manufacturing operations, and its adaptability to standardized production, its action under thermal manipulations and its degree of machinability for given physical properties.

The analyses of several drive shaft materials are shown in Table I.

There are various processes by which an axle shaft may be produced. It may be machined directly from bar stock, hammer-rolled, Witherow rolled, Ajax rolled or swaged.

Any one of these methods is very satisfactory where the shaft lends itself to a rolling process. When the shaft is designed with a large upset or flanged end, then forging is the most advisable.

Two of the most essential features in producing a shaft with a
large and deep upset is to maintain the proper grain flow in the
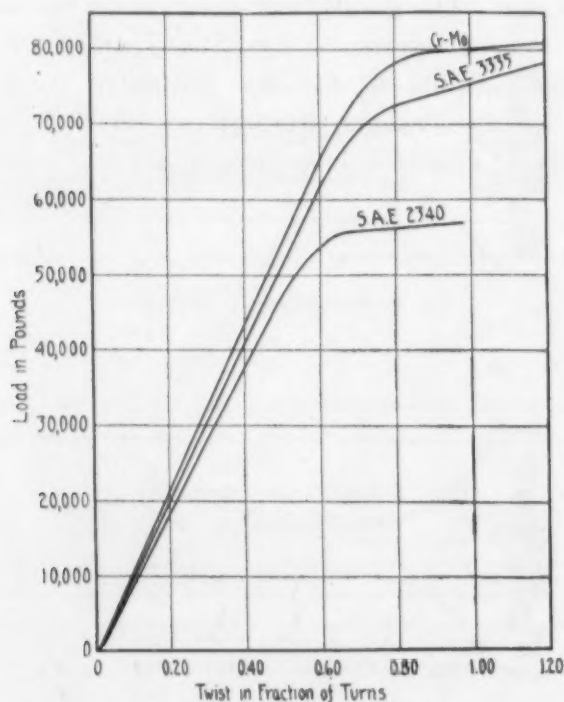flanged end and secure a steel that will successfully stand the abuse

Fig. 7—Curves Showing Distortion Produced on
Three Different Steels Heat Treated to the Same
Brinell Hardness.

of forging. Experimenting with steels of varying compositions has
shown that a shaft of this type cannot be successfully forged on

Table I
Chemical Analyses of Several Drive Shaft Steels

S.A.E. No.	Carbon Per Cent	Manganese Per Cent	Chromium Per Cent	Nickel Per Cent	Vanadium Per Cent	Molybdenum Per Cent
3140	0.35-0.45	0.50-0.80	0.45-0.75	1.00-1.50	..	..
3335	0.30-0.40	0.30-0.60	1.25-1.75	3.25-3.75	..	..
6135	0.30-0.40	0.50-0.80	0.80-1.10	..	0.15 Min.	..
4130	0.25-0.35	0.40-0.70	0.50-0.80	..	..	0.15-0.25
4140	0.35-0.45	0.40-0.70	0.80-1.10	..	..	0.15-0.25

a production basis from steels of all analyses. A steel that has
worked out very satisfactorily from all forging, heat treating and
machining angles is of the following analysis:

	Per Cent
Carbon	0.38—0.48
Manganese	0.65—0.85
Phosphorus	Max. 0.040
Sulphur	Max. 0.040
Chromium	0.90—1.10
Molybdenum	0.10—0.20

Steel of this composition flowed well in the dies and the percentage loss due to cracks, seams, laps and burns was smaller than with any other analysis tried.

Chromium-molybdenum steels appear to be well adapted for the manufacture of drive shafts. They may be subjected to unusually wide temperature variations for either hot working or heat treating. While the power required to hot forge this material is greater than for nickel, chromium or chromium-nickel steels, it does not decrease die life. It flows well in the dies but scales rather readily. This scale, however, is loose and does not adhere to the surface of the work as firmly as in the case of some of the other alloy steels, thus producing a cleaner forging with minimum cleaning charges.

Table II
Physical Properties of Several Drive Shafts

Tensile Strength Lbs./Sq. In.	Elastic Limit Lbs./Sq. In.	Elongation Per Cent	Red. in Area Per Cent	Brinell Hardness Number
Chromium-Molybdenum Steel				
204,900	186,750	11.5	48.0	418
206,250	188,100	12.0	47.0	402
198,000	177,350	12.5	49.0	387
205,700	189,200	12.0	48.0	418
S. A. E. 2340				
165,600	150,400	10.0	45.0	364
173,850	155,100	13.5	49.1	387
168,700	152,000	12.0	47.0	418
171,450	153,650	12.0	48.2	387
S. A. E. 3335				
177,200	166,250	16.0	58.5	364
181,900	160,350	16.0	54.9	387
185,400	173,100	15.5	55.9	364

From the standpoint of design, the physical properties of a material are important factors; from a cost angle, machining is a big item. The amount of machine work which has to be performed

on an axle shaft depends upon the design and method of manufacture, i.e. a semifloating shaft turned from bar stock will require more labor than if it had been previously forged to shape, whereas with the average full-floating design, it is usually cheaper to machine out of bar stock, unless a large quantity is required.

The ideal method of manufacturing is to finish the part in the heat treated condition. Warping and scaling of semi-machined parts are thus eliminated and the material once entering the machine shop is completed without the loss of time and confusion resulting from an intermediate heat treatment.

Drive shafts require high physical properties, consequently a high Brinell hardness must be maintained, usually within the range of 302 to 418. This combination makes it rather difficult to machine in the heat treated state on a production basis and this can only be accomplished successfully by the selection of the proper materials and giving them a satisfactory heat treatment.

Not all steels can be readily machined at this hardness. Chromium-molybdenum steels are unique in that they possess exceptional machining qualities and can be machined on a production basis at a higher Brinell hardness than any of the more common alloys.

The principal machining operations on a semifloating shaft which has been rolled or forged are turning the spline end, turning the thread diameter and short taper, cutting the keyway and splining. All of these operations are performed on a rapid production basis, machining chromium-molybdenum steels, heat treated to a Brinell hardness of 364 to 418.

The heat treatment of chromium-molybdenum steels for drive shafts does not present any new problems. This steel is not susceptible to the deleterious influence of high temperatures and suitable heat treatment will develop a very fine microstructure as shown in Fig. 8, which shows the structure of a drive shaft quenched at 1625 degrees Fahr. in oil with a 1000-degree Fahr. temper. The physical properties of this shaft are:

Tensile strength, lbs. per sq. in.	160,900
Elastic Limit, lbs. per sq. in.	150,800
Elongation in 2 ins. Per Cent	17.5
Reduction in Area, Per Cent	56.4

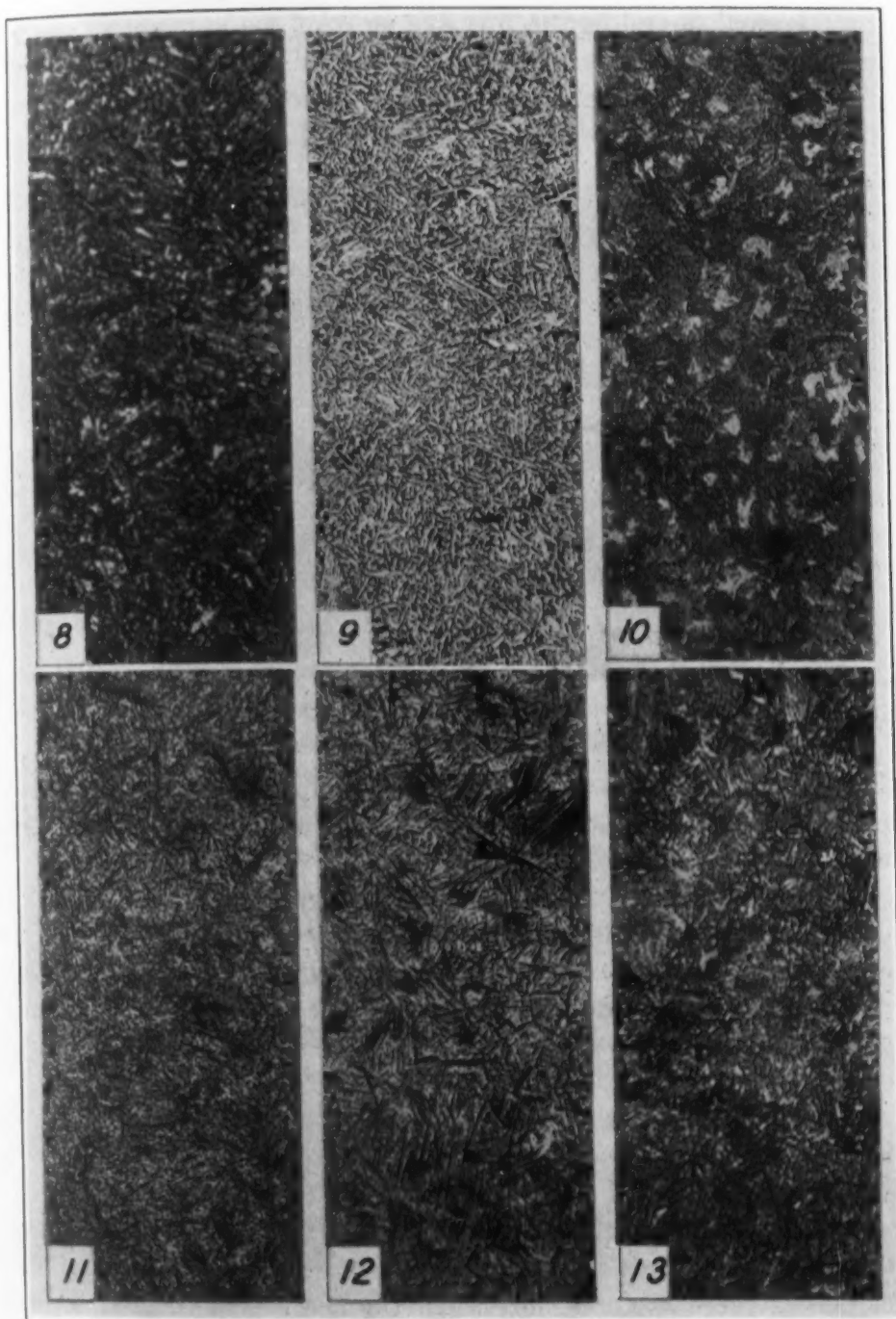The small addition of molybdenum permits great hardness both

Fig. 8—Photomicrograph of a Chromium-Molybdenum Steel Drive Shaft Quenched in Oil at 1625 degrees Fahr., Tempered at 1000 degrees Fahr. Fig. 9—Photomicrograph of a Chromium-Molybdenum Steel Shaft in the Forged Condition. Fig. 10—Photomicrograph of Same Steel As Fig. 9 But Normalized at 1650 degrees Fahr. Fig. 11—Photomicrograph of Same Steel as Fig. 9 But Normalized and Quenched in Oil. Fig. 12—Photomicrograph of Same Steel as Fig. 9 But Normalized and Quenched in Water. Fig. 13—Photomicrograph of Same Steel as Fig. 9 But Normalized, Quenched and Tempered in Lead at 1025 degrees Fahr. All Magnifications × 100.

on the surface and depth, but like most of the automotive steels it requires a heat treatment to bring out its physical characteristics to the best advantage. The effect of various operations may best be judged by referring to photomicrographs Figs. 9, 10, 11 and

Fig. 14—Photomacrograph of a Typical Fatigue Fracture. Fig. 15—Photograph of a Torsional Break.

12, which were made on shafts forged from a heat of steel having, carbon 0.38 per cent, manganese 0.59 per cent, chromium 0.86 per cent, molybdenum 0.16 per cent.

These steels have a slow quenching rate and require a less drastic quench for deep and complete hardening. They have an exceptional resistance to tempering and when being softened they require either a higher temperature or a longer time than most of the common alloys, hence their greater resistance to dynamic stress or to fatigue.

Drive shafts fail mostly in torsion, occasionally a shaft which has failed in fatigue can be found. A typical fatigue fracture is shown in Fig. 14 and a torsional break in Fig. 15.

Shafts are designed using a sufficient factor of safety and materials selected and heat treated so as to prevent failures of this type, but there are occasions when the shafts are stressed beyond their full capacity and thus failure becomes inevitable.

INCLUSIONS IN IRON

*A Photomicrographic Study**

By C. R. WOHRMAN

CHAPTER I

INTRODUCTION

1. An Outline of the Inclusion Problem and of the Author's Work

INCLUSIONS or enclosures in metals have early attracted the attention of scientists. Sulphide inclusions in iron were described and studied some 25 or 30 years ago by Andrews, Le Chatelier and Arnold who recorded some remarkably accurate observations on the subject. Their work was continued and supplemented by Heyn and Bauer, Stead, Law, Ziegler and Matveieff, and, in more recent years, by Levy, Röhl, McCance, Hibbard, Comstock, and a number of other investigators.

The subject of inclusions appears, nevertheless, to have received less attention than it deserves. The genesis of inclusions, their characteristics and habits, on the one hand, and their effects on the useful properties of metals, on the other, are less well understood than would appear from a casual acquaintance with the subject.

The reason for this lies, undoubtedly, in the great complexity of the subject requiring for its study not only ingenuity and skill, but also precision equipment and laboratory facilities of the highest order. The subject is, furthermore, so broad as to require for its understanding the correlation and assembling of a great variety of detailed data secured from a variety of diverse sources and experiments.

A comprehensive study of inclusions in iron and steel, for example, implies not only a study of the finished product but a detailed investigation into the entire process of making the product

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as well. To begin with, there is the ore, the pig iron, the scrap, the furnace lining—all of which supply inclusion-forming material. A variety of slags are produced in commercial practice, every one of which is a most complicated physico-chemical system. The molten metal itself, containing a variety of elements, is a system of great complexity. The effect of temperature and of the furnace atmosphere have to be considered. The viscosity of the metal and the slag, the phenomena of surface tension and of diffusion are factors of importance. The temperature of pouring, the varying practice of ladle additions, the speed of solidification and of subsequent cooling have an influence. These factors are, furthermore, closely intertwined and interdependent in their importance and effects. The study of any or all of them is troublesome on account of the high temperatures involved and the difficulty of separating the variables present.

A study of the inclusions already formed, such as found in commercial iron and steel, is also far from simple. Here the minuteness of the inclusions makes qualitative tests a task, and, in microscopic work, necessitates the use of high magnifications coupled with careful preparation of the samples.

All these difficulties constitute, of course, no valid excuse for neglecting the study of inclusions. Specifications for steels are becoming continually more rigid and standards more and more exacting. Can we, under the circumstances, neglect the influence of inclusions? Must we not issue "inclusion specifications" analogous to the specifications issued for the case of alloy-forming impurities? Recommendations to this effect have, indeed, already been made.

But, before we can formulate useful specifications, we must know the facts. The main issues of the problem of inclusions are:

I. What is the influence of inclusions on the useful physical properties of the metal? In particular, what is the influence of:

    1. The number of inclusions

    2. Their size and shape

    3. The kind of inclusion.

II. How can we govern inclusions? An answer to this implies:

    1. The ability to identify inclusions

    2. The knowledge of inclusions, i. e., of:

    (a) The conditions leading to their birth sources
    (b) The conditions surrounding their birth formation
    (c) Their habits
    (d) Their friends and enemies—conditions favoring retention and elimination.

The first of these issues is largely a problem in the strength of materials, the second one of physical chemistry.

The present research is concerned, primarily, with the second question, i. e., the study of how to govern inclusions, the problem being approached by a microscopic inquiry into the characteristics and the behavior of the more important inclusions found in iron. The present research is, thus, essentially a photomicrographic study of inclusions, limited to the case of inclusions in iron.

In particular, the present research concerns itself with a study of the characteristics and behavior of the inclusions created in iron by oxygen, sulphur and manganese, i. e., the inclusions ordinarily referred to as FeO, MnO, FeS, MnS, and their combinations. The study of silicates forms a subject by itself and could not be taken up in requisite detail.

The first chapter of the present paper is of an introductory nature. The methods used for making artificial known inclusions desired for the studies are described; the preparation of specimens, in particular the methods of polishing for inclusions, are considered next; finally, the technique of microscopic examination is dealt with.

The oxide, sulphide, and oxide-sulphide inclusions are then described in Chapters II, III and IV, respectively. Their appearance and typical occurrence is noted in each case, as well as their etching characteristics in the more common reagents used in metallographic work. Particular attention is paid to the constitution of the inclusions and the much disputed questions relating to their origin and behavior.

Chapter V serves to summarize and discuss the evidence thus obtained, and to correlate it with accepted theories and hypotheses about the nature of inclusions. The sources of inclusion-forming materials, the status of inclusions in the molten metal and their formation are discussed, and the conditions governing their size,

shape and distribution outlined. The behavior of inclusions, their occurrence at grain boundaries and preferential association with the pro-eutectoid elements, is discussed next. The problem of identification of inclusions is also touched upon. Desirable modifications and changes in Campbell and Comstock's "Method for the Identification of Non-Metallic Inclusions in Iron and Steel" are suggested. The influence of inclusions on the useful properties of metals is then briefly examined. The phenomenon of red-shortness receives especial attention and a new explanation for it is offered. The chapter is concluded with a brief reference to the problem of elimination of inclusions.

2. *The Preparation of Artificial Known Inclusions*

Inclusions, in most instances, have been studied in their natural state, i. e., in the form in which they appear in commercial iron and steel. Such studies are hardly capable of yielding the specific information that is essential for a satisfactory solution of the problem of inclusions.

Inclusions, ordinarily, appear in metals in the form of tiny globules and streaks which oftentimes, at ordinary magnifications, are barely visible. It is easy to understand that the effects of sundry chemical and other tests can be judged, on that account, only with difficulty. Unless we are well acquainted with the specific characteristics of known inclusions we cannot hope to identify and to interpret unknown inclusions. It is necessary, therefore, at the outset, to prepare artificial known inclusions and to study them first.

The idea of making artificial inclusions in not new. Matveieff[1] prepared a complete set of such inclusions by filling a wrought iron tube with the necessary inclusion material, heating the tube to about 2370 degrees Fahr. (1300 degrees Cent.) and forging it. This method has the serious drawback of not reproducing the conditions under which inclusions actually form. The extent to which the materials that make up inclusions react, and the way in which they react, depends to a great extent on the temperature at which the reactions take place. Representative artificial inclusions can, therefore, be prepared only by actually melting the metal and the

[1]*Revue de Metallurgie*, 1910, p. 447 et seq.
Revue de Metallurgie, 1920, p. 736 et seq.

inclusion-forming materials together. This latter method has been used by Arnold,[2] Röhl,[3] and a number of other investigators.

In the present research care was taken to avoid contamination of the melt by extraneous substances—a precaution which was not always taken by earlier workers. Electrolytic iron was used throughout, and chemicals of highest purity only were employed. An Arsem furnace was used for the preparation of the melts.

The corrosive action of some chemicals, notably of iron oxide and manganese proved detrimental to both the alundum (fused alumina) crucibles employed, and the purity of the melt. In order to avoid this and, at the same time, to prevent the escape
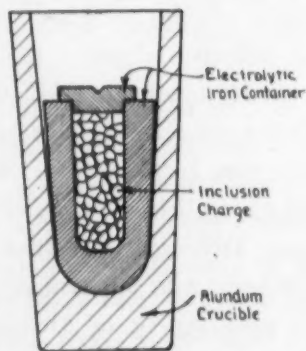
Fig. 1—Diagram Illustrating Crucible in Which Sample Melts Were Made.

of the more volatile charges (sulphur, for example) the melts were prepared in securely closed containers of vacuum-melted electrolytic iron placed, in turn, into the alundum crucibles. (See Fig. 1). The charge, then, would usually be absorbed by the iron while the latter was still solid or semi-solid and the crucible upon final melting was exposed merely to the corrosive effect of the alloy, which proved to be negligible. This arrangement had the further theoretical advantage that impurities insoluble in the iron (and, as is usually the case, having lower melting points than iron) would undisturbedly[4] melt into one lump inside the container and float bodily to the top of the melt upon fusion of the enclosing walls.

All "sulphide" melts were done in vacuo, most of the "oxide" and "oxide-sulphide" melts in air. In either case the temperature

[2] *Journal,* Iron and Steel Institute, 1914, I, p. 396 et seq.

[3] *Carnegie Scholarship Memoirs,* Iron and Steel Institute, 1912, p. 28 et seq.

[4] There is no stirring action in the Arsem furnace.

was raised gradually, the melting point of the charge being reached, ordinarily, in 30 to 40 minutes. The metal was kept molten for at least 5 minutes during which period the temperature continued to rise.[5] Ample opportunity was thus given for such supposedly agglomerated inclusion material as was insoluble in the metal to float to the top. Next, the temperature was gradually lowered, at first slowly, so as to permit slow solidification and unrestrained segregation, then more rapidly. Normally, the charge was cooled to a dull red in the course of 30 to 40 minutes.

In the case of air-melts it was found usually convenient (and sometimes necessary to supply additional inclusion-forming material after the melting of the original charge. This was accomplished by dropping pellets (about 5 millimeters in diameter) onto the surface of the molten metal. In all such cases the time required for the melting or absorption of the added material was noted, and the metal was kept molten correspondingly longer.

The prepared ingots weighed, on the average, about 60 grams (2 ounces). This size, although dictated to a certain extent by the capacity of the furnace, was chosen for the convenience in the further preparation and study of the specimens. The ingots, in most cases, were sawed into halves, longitudinally; one half was polished for microscopic examination, and the other half reserved for chemical analysis. A complete section of each ingot was thus secured for examination at a minimum of labor.

Accurate chemical analyses of the melts were kindly made by the well-trained staff of the chemical laboratory of the American Rolling Mill Company. These analyses, together with other essential information about individual melts, are given in Chapters II, III and IV.

3.   *Polishing for Inclusions*

The preparation of the samples for microscopic examination was a tedious task. Polishing of specimens for microscopic work is distinctly an art, and polishing for inclusions a very special art. A "science" of polishing is as yet not in existence.

The nature of polish has been studied by a number of investi-

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[5]Facilities for reliable measurements of the temperature in the vacuum furnace were, unfortunately, lacking.

gators,[6] and appears to be fairly well understood. A rather sharp line is usually drawn between the action of abrasives fixed to a rigid base, grinding, and the action of finer "loose" abrasives used on a wetted cloth. The former is taken to imply cutting or ploughing of grooves, the latter, flow, with the attendant generation of amorphous metal. In the opinion of the writer the difference between the two processes is one of degree, not of kind. Flow of the metal, at any rate in the case of soft metals, takes place on grinding just as surely as it does on polishing proper. It is a logical consequence of the reaction of the metal to the stresses imposed upon it, and these stresses differ only in degree.

In the last analysis, grinding and polishing of a surface imply "working" that surface. Forces ever-changing in magnitude and direction are exerted on the surface layer of the metal, the stresses imposed being in excess of the strength of the metal, or its resistance to deformation. Mechanical twinning[7] will take place, followed by "fragmentation," which, in the writer's opinion, implies merely the substitution of an extremely fine grain for the preexisting coarser grain. The resulting very fine-grained aggregate is, naturally, much harder than the original metal and represents the utmost in strength and resistance that the metal is able to command against the forces of polishing. The assumption of an amorphous phase is superfluous. In fact, recent X-ray studies have shown that heavily polished surfaces of metals gave no evidence of an amorphous state.[8]

The process of polishing appears to be a simple one requiring merely patience, especially in the case of pure iron and other soft metals. On attempting to analyze the process, the complexity of the problem becomes at once apparent.

Indeed, what basic facts are known to us that could guide us intelligently in the choice of the particular cloth and powder

[6]Robert Hooke, "Micrographia". Observation II.
Lord Raleigh, *Proceedings*, Royal Institute, 1901, 16, 563.
G. T. Beilby, *Proceedings*, Royal Society, 1903, 72, 218, 226.
　　Philosophical Magazine, 1904, 8, 258.
　　Faraday Society, June, 1904.
　　Journal, Society of Chemical Industry, 1903, 22, 1166.
　　Journal, Institute of Metals, 1911, VI, 2.
F. Osmond and G. Cartaud, *Revue Generale Sciences*, 1905, 16, 51.
W. Rosenhain, "Physical Metallurgy", 2nd edition, Part I, Chapter II.

[7]See L. B. Pfeil, "The Deformation of Iron," Iron and Steel Institute, *Carnegie Scholarship Memoirs*, 1926, p. 320 et seq.

[8]R. J. Anderson and J. T. Norton, "X-Ray Evidences vs. the Amorphous-Metal Hypothesis," *Transactions*, American Institute of Mining and Metallurgical Engineers, January, 1925.

to be used for polishing a given metal or in the choice of the speed of the wheel, the proportion of water in the polishing mixture, or the amount of the mixture to be applied? To those who know, the sensitiveness of a good polish to these and related variables need not be emphasized. But more than that, what are the fundamental considerations that led us to assume the combination of a cloth, an oxide powder, and water to make the ideal polishing combination? Perhaps we should use a metal base for the powder —lead, for example—and lubricate it with oil,[9] or, perhaps, polish with a paraffin disk lubricated with a soap solution?[10] And so on, ad infinitum.

The experience of earlier workers in the field of metallography and related fields is available to guide us. But experience based, as it is, on rather incomplete trials alone, and not substantiated by analytical experiments, nor logical deductions, cannot convince anyone of offering the best solution.

The established experimental facts, and attendant fundamental considerations, as they appear to the writer, are summarized below. The main items detrimental to a good polish are:

　　　　　I.　Too deep a flowed layer.
　　　　　II.　Pits.

I.　The depth of flow is a function of:
　　　1.　The stresses acting during polishing:

　　　　　(a)　The greater the pressure ⎫　the greater will
　　　　　　　　　　　　　　　　　　　　⎪　be the forces
　　　　　(b)　The greater the speed　　 ⎬　exerted per unit
　　　　　　　　　　　　　　　　　　　　⎪　area of the
　　　　　(c)　The finer the powder　　　⎭　surface polished.

　　　2.　The plasticity or softness of the metal:
　　　　　(a)　The more readily the metal yields the more
　　　　　　　　flow will be induced by a given stress.

　　　3.　The polishing combination:
　　　　　(a)　Character of abrasive and lubricant (influence rather problematical).

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[9]Promising experiments with this combination are being conducted in Professor L. C. Graton's Laboratory at the present.

[10]Recommended by R. G. Guthrie, TRANSACTIONS, American Society for Steel Treating, March, 1925.

(b) Manner in which abrasive is held:
>
> Abrasives attached to a rigid base induce
> less flow than those used in "loose" form.

II. Pits, irrespective of the character of the material polished,
are induced primarily by:

1. Abrasives applied in the "loose" form, especially
   the grades used for intermediate polish; the effect
   is aggravated by a fluffy soft cloth and high speed.

2. Vibration of the polishing wheel and related causes
   which imply sudden changes in the polishing
   stresses.

The main requisites for obtaining a good polish are therefore
as follows:

1. The use of abrasives fixed to a rigid base.
2. A "gentle touch" and "slow speed" throughout all
   operations, especially in the case of the softer metals.
3. Polishing equipment free from vibration.

Polishing for Inclusions

The preparation of a metal for the microscopic examination
of inclusions contained in it implies first and foremost the pres-
ervation of these inclusions.

This seems too obvious a fact to need mentioning, yet, judging
from some of the pictures appearing in the literature, this fact is
not generally understood. Fig. 2 is a reproduction of a photo-
micrograph published with a well-known paper on inclusions in a
well-known journal. It purports to be a photomicrograph at $\times$ 1000
of oxide inclusions. It is a picture of a group of small pits sur-
rounding a larger pit. Numerous instances of this sort could be
cited. Holes should never be called inclusions even if they are
suspected to have contained inclusions.

Inclusions, whether they appear in the metal in the form of
globules, as elongated streaks, or as angular bodies, have in all
and every case clear-cut and well-defined outlines. Fig. 3 shows
the appearance, under the microscope, of properly polished and
preserved iron-oxide inclusions.[11] The reader is invited to compare

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[11] The specimen was prepared by W. McGohan of the research department of the American
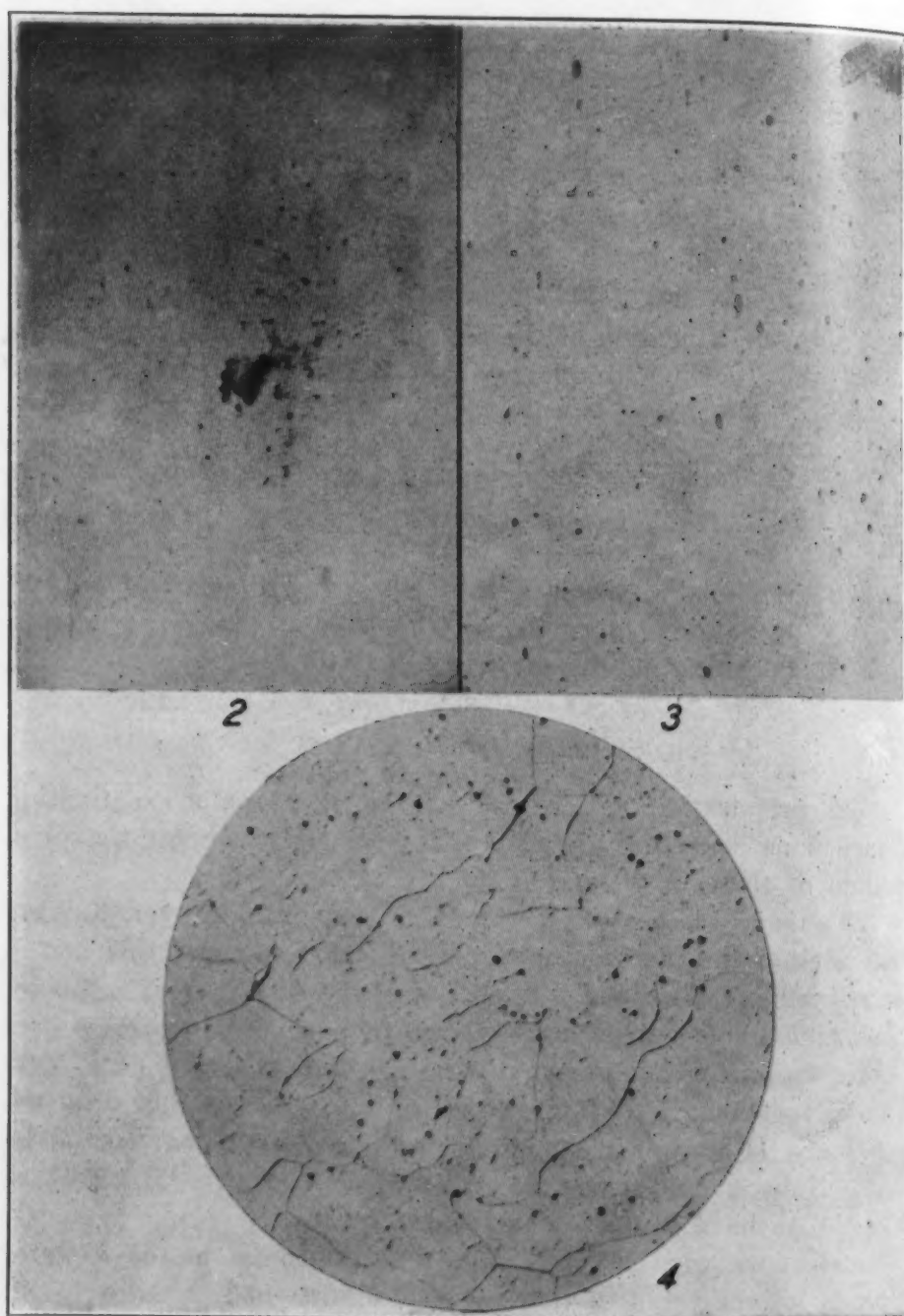Rolling Mill Company.

Fig. 2—Reproduction of a Photograph of "Oxide Inclusions" Published in a Well-known Paper. Actually it is a Large Pit Surrounded by Smaller Pits. × 100. Fig. 3—Appearance of Properly Polished Oxide Inclusions. Note the Definite Outlines and Coloration. × 100. Fig. 4—Polishing Pits Simulating Inclusions in Vacuum-melted and Lightly Etched Electrolytic Iron. × 100.

the appearance of these inclusions with that of the spots of Fig. 4. The latter are pits in an improperly polished piece of vacuum-melted electrolytic iron, essentially free from gases and inclusions of any sort.

The preservation of inclusions is difficult. Some[12] believe that there is no cohesion between the metal and inclusions and that the latter are obliged to drop out whenever the plane of the section lies below their maximum diameter. According to the observations of the author this is not the case. A definite, though weak, cohesion exists; at any rate in metals in the cast or forged condition.

It is the pitting action of polishing that causes the trouble. Pitting is noticeable already in the case of a plastic metal; it is only natural that it should prove detrimental to the brittle inclusions and the weak joints between the metal and inclusions.

Realizing this the author endeavored to reduce pitting to a minimum. At first F. F. Lucas' method[13] was used. The results were not perfect, yet quite satisfactory when Lucas' specifications were followed exactly, and the polishing carried out on laps with a direct drive. The friction drive laps, with their inherent vibration, were found to be detrimental to inclusions, no matter how carefully the specimens were polished otherwise. Further work showed that the intermediate alundum lap was harmful to the inclusions, and ways were sought to avoid it altogether. A description of the various trials and re-trials will be spared to the reader.

A more or less satisfactory solution was finally found in a method which practically disposes of the use of "loose" abrasives. Preliminary hand grinding on emery papers was followed directly by final polishing on a vibrationless disk covered with a billiard cloth of dense weave to which jeweler's rouge in cake form was applied.[14] This rouge, when spread on the wheel, becomes firmly lodged in the close weave of the cloth and does not float around in the water as polishing powders usually do. We thus approximate to the case of an exceedingly fine abrasive attached to a rigid base. This behavior of the rouge is explained by the fact that the binder employed in making the cake, while soluble in benzene, xylene, chloroform, and related organic liquids, has a repelling

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[12]J. O. Arnold, *The Metallographist*, 1900 p. 273-74.

[13]Appendix III of Albert Sauveur's "Metallography", 3rd edition, 1926.

[14]The polishing combination: billiard cloth and cake rouge, was devised by W. McGohan of the American Rolling Mill Company.

action on water. Water, in fact, does not wet the rouge-covered disk, and acts merely as a lubricant.

A detailed description of the steps employed by the author in polishing for inclusions follows:

1. Very light grinding on a fine emery wheel.
2. Flattening of the surface by hand grinding on "India" oil-stone (coarse).
3. Grinding by hand on French emery paper beginning with No. 1 and finishing with No. 0000. No oil or kerosene should be used —at least not on the final papers.

    The pressure exerted should be very slight on the coarser grades and practically nil on the finer.
4. Polishing on a disk covered with a good grade of moistened billiard cloth and charged with rouge by pressing a cake of finest jeweler's rouge against the revolving wheel. Water is dropped at a constant rate on the wheel which is revolved at about 700 revolutions per minute. If the rouge sticks to the specimen the amount applied is too heavy, or else there is not enough lubrication by water. In the beginning of the operation a moderate pressure can be exerted on the specimen which is to be moved about on the wheel and rotated to insure an even polish. Toward the end of the operation, which should be completed in 5 to 10 minutes, no pressure at all should be used. It is imperative that the wheel be vibrationless. (The author used a belt-driven ball-bearing machine manufactured by a well-known concern).
5. Washing of the specimen in benzene and alcohol and touching it for half a minute or so to a very slowly (100 revolutions per minute) revolving lap of kitten's ear cloth charged with a paste of finest magnesium oxide. This operation disposes of traces of rouge adhering to the specimen and adds to the quality of the polish.

If due care was taken in all operations the inclusions were found to be preserved in perfection. Whenever the time was limited, however, and the materials inferior,[15] the results suffered correspondingly. The amount of flow, caused by the rapidly revolving rouge wheel, was often found to be in excess of the allowable

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[15]Hubert emery paper, in particular, was found to be of an unsatisfactory quality of late.

limit, especially when the finishing on emery paper was imperfect. This did not interfere, however, with the study of inclusions.

The example of the rouge wheel serves to underline the merits of a "fixed" abrasive and suggests a way of preparing such abrasives for fine as well as intermediate polishing.

4. Microscopic Examination of Inclusions

Magnifications Used. The inclusions met with in commercial iron and steel are usually small. A maximum diameter of 0.01 millimeters is seldom exceeded except in the case of inclusions markedly elongated by hot work. The structure of individual inclusions, accordingly, can be seen with any certainty only at high magnifications. The effect of etching treatments on inclusions, similarly, can be observed clearly and unmistakably only at relatively high powers. On the other hand, if the distribution of inclusions is studied, or their relative abundance, low magnification must be used.

The author found the following magnifications convenient:

1.   3½ —for studying the relation of inclusions to the existing grains and to the primary dendritic grains of the iron.
2.   100 —for a general survey of the distribution, predominant form, and "density" of inclusions.
3.   500 —for observing etching effects on individual inclusions and groups of inclusions.
4.   2500—for detailed study of the structure of complex inclusions.

Each specimen was examined successively at each of the magnifications stated.

Facts About Photomicrography. It will, perhaps, be helpful, in this connection, to point out some of the facts about low and high magnifications in photomicrography that have not been properly emphasized by earlier investigators. They can be stated as follows:

1. If two or more constituents are present in a metallographic specimen their differences become apparent:
    (a) on account of inherent differences in color and brilliancy

   (b) on account of artificial color differences induced by etching and tinting treatments

   (c) on account of a relief effect created by differential dissolution of the constituents by etching reagents, or by polishing.

2. Relief causes shadows which are the more confusing the higher the relief, the finer the structure and the lower the magnification used. (Pearlite is an example—see Technical Publication, No. 14, American Institute of Mining and Metallurgical Engineers, September 1927, p. 9).

3. Differences due to coloration appear the more pronounced the higher the magnification used.

In other words, while contrasts due to relief are diminished, true color differences are greatly enhanced by high magnifications.

How to Distinguish Inclusions.—The bearing of these facts on the microscopic study of inclusions is obvious. High magnifications will not only facilitate distinction on the basis of faint differences in color and shade, but will unmistakably point out whether or not we are dealing with an inclusion or with a pit.

Whenever a light-colored inclusion is observed at low powers, say $\times$ 100, we can be sure that it is an inclusion. If a black "inclusion" is seen, however, it may be an inclusion, but it may also be a hole appearing dark due to a shadow effect.

Fig. 5 exhibits an assembly of such dark "inclusions." Their outlines are clear cut and definite, their shape is rounded and typical for inclusions, their color is dark, they are, furthermore, not reduced by hydrogen, nor attacked by sodium picrate,—they must, on the basis of our standards for identification, be silicates. It is possible that they were silicates. We do not know, because at the present they are just holes. Fig. 6 shows two of these holes at a magnification of $\times$ 500. Beautiful interference rings are seen, formed by reflection of the light from the walls of the accurately spherical depressions. No material inclusion, of course, is capable of producing such light effects unless, indeed, it be a perfectly transparent glass. The possibility of such glasses occurring as inclusions is remote; still, in case of doubt, a scratch test will tell the story.

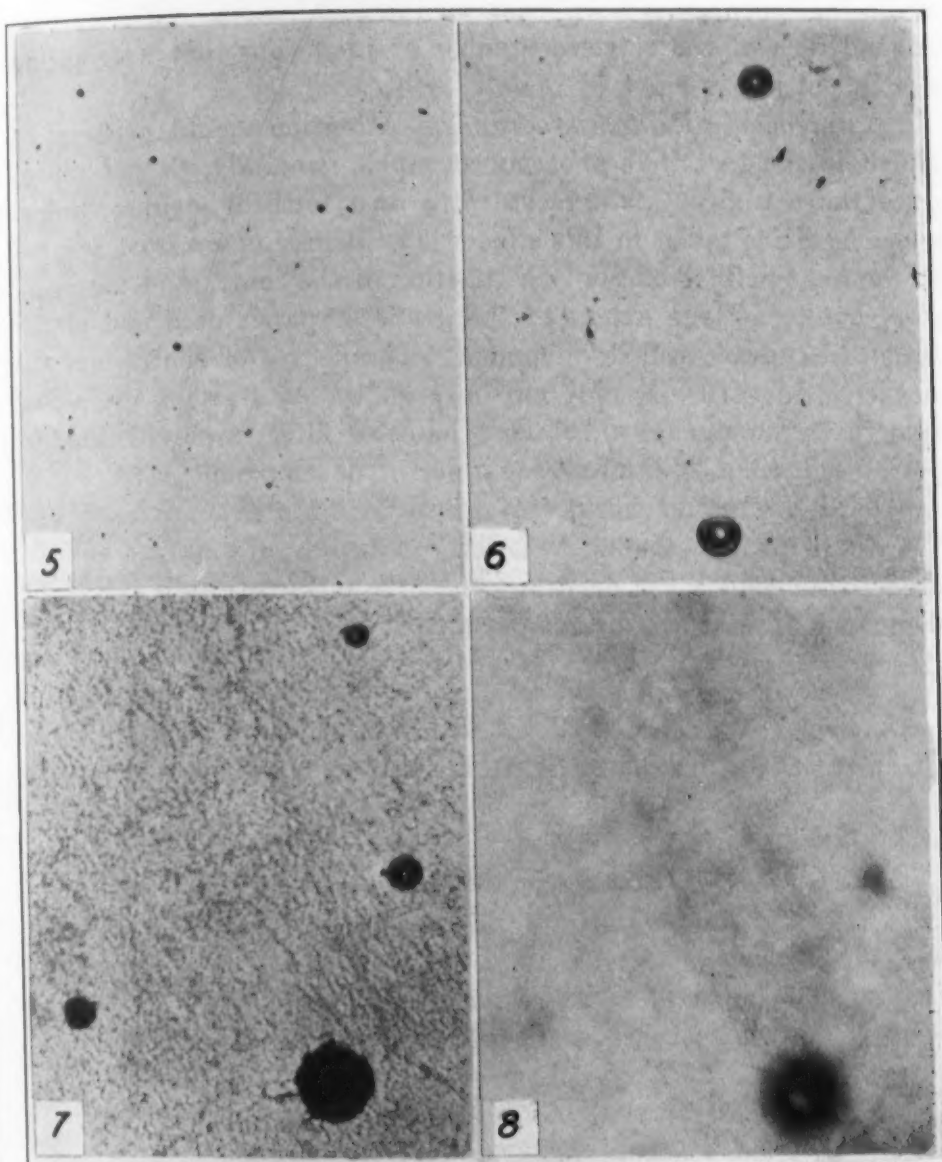In some exceptional cases the shape of the hole is such as to simulate an inclusion even at the higher magnifications. The large

Fig. 5—Are the Black Spots Inclusions? Mag. × 100. Fig. 6—View of Two of the Spots of Fig. 5 at × 500. They are Spherical Holes. Fig. 7—Note the Larger "Inclusion". × 500. Fig. 8—Same as Fig. 7 Viewed with the Objective Focussed Toward the Bottom of the "Inclusions". The Light Spot Which Appears Indicates a Hole. × 500.

"inclusion" of Fig. 7 is an example. The final test, in such cases, consists in focusing on the bottom of the "inclusion." If it is an inclusion it will remain dark—merely fading in clearness,—if it is a hole, a bright area will appear when the lens is focused on the bottom (Fig. 8).

This test of changing the focus can be applied conveniently

while the specimen is being examined at low powers, and gives then a good idea of the relative number of inclusions that were pitted out in polishing.

Contrasts in Photomicrographs.—Attention should, perhaps, be called to the fact that photomicrographs, generally, do not reproduce the actually existing contrasts in a faithful manner, unless special care is taken to this effect. The degree of contrast secured in the final print is not only a function of the contrast of the negative, but to a large extent of the grade of paper used and of the time of exposure and development. The degree of contrast of the negative, in turn, depends not only on the contrast of the actual structures photographed, but on the color filter employed, kind of plate used, time of exposure, manner of development, etc.

In the present work, "Wratten M" plates were used and "Azo" printing papers. Whenever desirable, the author endeavored to reproduce the existing contrasts as faithfully as his judgment and working conditions permitted.

CHAPTER II

OXIDE INCLUSIONS (AND SILICATES)

I. *Review of Existing Knowledge*

T HE present chapter deals primarily with iron oxide and manganese oxide inclusions in iron.

A vast amount of work has been done on these oxides and on their equilibrium relations in steel making processes. Oxides of iron, in particular, have been investigated in great detail. An idea of the magnitude of this work can be gained from the list of references appended to this chapter,[16] the list being far from complete. The surprising degree of confusion existing in this literature and the lack of agreement in respect to many important and fundamental points serves to emphasize the complexity of the problem and the difficulties encountered in experimentation. No attempt will be made (and cannot be made within the scope of this work) to go into these problems in any detail. It will be helpful, however, to review briefly such data as are most important for the problem of inclusions.

Iron Oxides.—Both ferric oxide, or hematite (Fe_2O_3), and ferroferric oxide, or magnetite, occur naturally and are well-known. Both exhibit polymorphism as was shown by Sosman (14). At temperatures above 2010 degrees Fahr. (1100 degrees Cent.) these two oxides form a continuous series of solid solutions (20,41); the extent of solid solubility at lower temperatures is not definitely known; it appears, however, to be small.

Ferrous oxide, FeO, has never been isolated in the pure state, chemical analyses revealing always the presence of some Fe_2O_3. Hilpert and Beyer (25) ascribed this to the formation of solid solutions between FeO and Fe_3O_4. As pointed out by Eastman (29), the presence of Fe_3O_4 in carefully prepared FeO could equally well be accounted for by the instability of FeO, with respect to Fe_3O_4 and Fe, below some definite temperature. According to this conception ferrous oxide prepared at a higher temperature would react partly on cooling, to form Fe_3O_4 and iron:

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[16]Numbers in brackets refer to the list of references appended to this chapter, not to the list at the end of the paper.

$$4FeO = Fe_3O_4 + Fe$$
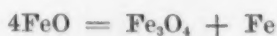
The instability of FeO at low temperatures has been verified by Chaudron (13). The existence of solid solutions between FeO and Fe_3O_4 has, however, also been verified,—by Matsubara (42),—who found Fe_3O_4 to be soluble to a limited extent in FeO at temperatures below 2010 degrees Fahr. (1100 degrees Cent.). It is suspected that a continuous series of solid solutions exists at higher temperatures. A suboxide of iron, Fe_3O, is believed, by Schenck (41), to be stable in the presence of FeO and Fe_3C at relatively low temperatures.

The question of solubility of the oxides in iron merits especial attention. Indeed, the entire problem of elimination of inclusions hinges on the question whether inclusions are suspensions in the molten metal, or whether they are precipitated from solution on solidification; or even later, on cooling of the already solid metal. Only the ferrous oxide, FeO, needs to be considered in this connection since the higher oxides are reduced, in the presence of molten iron, to FeO.

Ferrous oxide, until recently, was held by many metallurgists to be insoluble in iron, despite the fact that the oxide content of the metal bath was observed to be a function of the composition of the slag and of the temperature. This is, surely, indicative of an equilibrium relation that could not be brought about by mechanically suspended matter.

Le Chatelier and his school were, perhaps, the first to advocate the solubility of oxygen in iron. According to Le Chatelier, oxygen is soluble even in solid iron producing, on segregation, the dendritic heterogeneity of cast steel and the banded structure observed in forged material. This view has been contested by Stead who has conclusively shown that phosphorus, and not oxygen, is responsible for the observed segregation phenomena.

In 1915, W. Austin (45), on the basis of a study of artificially prepared oxygenated alloys, concluded that, "it is conceivable that the oxide is soluble in molten iron, but is rejected on solidification."

In 1918, A. McCance (46), on the basis of a study of open-hearth reactions, stated that, "all the evidence is favorable to the view that FeO is in solution in liquid steel."

Finally, in 1924, Tritton and Hanson (47) succeeded in preparing containers capable of holding molten iron oxide, and were

thus enabled to study the iron-oxygen system. They found that molten iron dissolves up to 0.21 per cent oxygen while solid iron can hold in solution only some 0.05 per cent. The solubility of iron oxide in iron is further substantiated by the researches of Eastman and Evans (33), Schenck (41) and others who investigated the iron-oxygen-carbon and iron-oxygen-hydrogen systems.

Additional data of interest about FeO are summarized in the table below where they can be compared with the corresponding data for MnO.

	Mol wt.	Crystal system	Melting Point	Density (20°C)	Heat of Formation Cals. per gram atom Oxygen
FeO	71.84	Cubic NaCl type	1420°C	Unknown	56
MnO	70.93	Cubic NaCl type	1650°C	5.18	73

Manganese Oxide.—Of the great number of manganese oxides only MnO is of interest from the inclusion standpoint. A mineral of this composition, manganosite, is known to exist, but is, however, relatively rare.

In iron, MnO is shown to be formed according to the reaction

$$Mn + FeO = Fe + MnO$$

in the course of "deoxidation" by manganese. This reaction is reversible and proceeds in a manner dependent on the concentration of the factors involved and on the temperature, i. e., until equilibrium is established. The equilibrium conditions have been studied by a number of investigators (24, 37, 38, 39).

The solubility of MnO in molten iron has not been determined. From a consideration of the equation given above it would appear that MnO must be soluble in iron, even if only to a small extent. Indeed, manganese and FeO are known to be soluble in molten iron; the existence then, of equilibrium relations of these factors with MnO, in the liquid bath, proves the solubility of MnO in that bath.

Methods for identifying MnO (and FeO) inclusions have been given by a number of investigators (43, 46, 50). It is further generally advocated that MnO inclusions are less objectionable than inclusions of FeO. One is thus led to believe that inclusions of MnO have been definitely identified in iron and steel, and that such inclusions have an existence apart from FeO inclusions.

S. L. Hoyt (52) points out, however, that "MnO as a foreign inclusion has never been identified." He attributes this to the similarity in appearance of MnO and MnS and the consequent possibility of the oxide having been mistaken, at times, for the sulphide which is so frequently described.

2. *Experimental Melts*

Table I summarizes the information about the experimental oxide-bearing alloys prepared by the writer.

Table I
Oxide Experimental Melts

Melt	Charge (grams)		To Yield, Per Cent	Chemical Analysis, Per cent	Remarks
0-1	El. Fe	68.02	Fe 99.87		Heated slowly in vacuo to about 1400 degrees Cent. (3 hours); the crucible then cracked and heating was discontinued. The specimen was allowed to cool in vacuo.
	Fe₂O₃	0.30	O₂ 0.13		
		68.32			
0-2	El. Fe	71.2			Melted in air; 0.8 gr. of Fe₂O₃ were charged in the container and an unknown quantity dropped into the crucible after the metal had melted.
	Fe₂O₃	?			
0-3	An ingot iron crucible was heated in vacuo with a mixture of 70 grams of electrolytic iron and 30 grams Fe₂O₃ to about 1400 degrees Cent. and slowly cooled.				
0-4	El. Fe	53.5	Fe 93.05	Mn 0.300	Melted in air. Of the oxide charge 1.7 gr. were added in the form of pellets dropped into the crucible after the metal had melted. The charge solidified quietly.
	Mn₂O₃	4.0	Mn 4.85		
		57.5	O₂ 2.10		
0-5	El. Fe	62.35	Fe 95.94	Mn 0.087	Melted in air. Of the oxides 0.9 gr. was added in the form of pellets. Solidification was accompanied by evolution of gases.
	Mn₂O₃	2.05	Mn 2.14		
	Fe₂O₃	2.20	O₂ 1.92		
		66.60			
0-6	El. Fe	52.90		Si 0.056	Melted in vacuo.
	Ferric Silicate	1.50			
		54.40			
0-7	El. Fe	53.90		Mn 0.50	Melted in air. Several pellets of a mixture of Fe- and Mn-silicate were dropped on the top of the melt and were well absorbed. The crucible near the top was slightly corroded.
	Mn Silicate	0.95		Si 0.020	
	Fe Silicate	0.65			
		55.50			

3. *Iron Oxide Inclusions*

The melt O-1 was intended to yield pure iron oxide inclusions with which the writer was desirous to acquaint himself thoroughly before taking up the study of other inclusions. At the time, only

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a rather poor grade of crucible was available in the laboratory, necessitating a very gradual and slow heating. This precaution was taken, yet the crucible cracked on reaching (after 3 hours heating) a temperature of about 2550 degrees Fahr. (1400 degrees Cent.). Heating was then discontinued and the charge allowed to cool in vacuo. The electrolytic iron container was found to have shrunk around the oxide-filled hole exhibiting upon sectioning (and polishing) the shape illustrated in Fig. 9. The hole had welded up in a perfect manner, no sign of porosity being discernible even at high magnifications. And, curiously, not a sign of the oxide could be found, although the quantity charged was in excess of the amount reported to be soluble in solid iron. The oxide, clearly, had left the container diffusing (upon reduction to FeO) through the iron and dissociating in vacuo. This experiment substantiates the solubility of iron oxide in iron and serves to caution against annealing in vacuo when the effects of a given oxygen content in iron are to be studied.

The melt O-2 being the second melt was prepared in air and exhibited the typical gray inclusions of FeO, illustrated in Fig. 16. These inclusions were found to be uniform in appearance with no indication of a duplex structure, and were distributed fairly uniformly throughout the ingot. The inclusions resisted effectively etching attempts with dilute nitric acid, chromic acid, boiling sodium picrate and boiling potassium hydroxide, it succumbed, however, to a saturated solution of stannous chloride in alcohol. It appeared, therefore, that the systematic "Method for the Identification of Non-Metallic Inclusions in Iron and Steel" of Campbell and Comstock led to correct results in this instance.

Sulphur printing[17] was also tried. This treatment affected some of the smallest inclusions to a slight extent, but had, however, no pronounced effect otherwise.

Magnetite Inclusions.—In the course of a parallel study of inclusions in ingot iron the writer observed typical iron oxide inclusions carrying (usually in their middle) tiny crystals of a dark gray constituent. (See Fig. 14.) These crystals were unfortunately

[17]Sulphur printing was used by the author throughout the work on inclusions as a convenient supplementary test. "Azo" printing paper was soaked in a 2 per cent H_2SO_4 solution, placed on a glass plate and the polished specimen, previously wetted, pressed firmly against the paper. The time of contact, unless specified otherwise, was 20 seconds. Since the specimens had a tendency to tarnish somewhat in the course of this procedure, sulphur printing was usually followed by a very slight "touching up" on the magnesium oxide lap. This restored the brilliancy of the polish without diminishing the etching effects of the treatment.
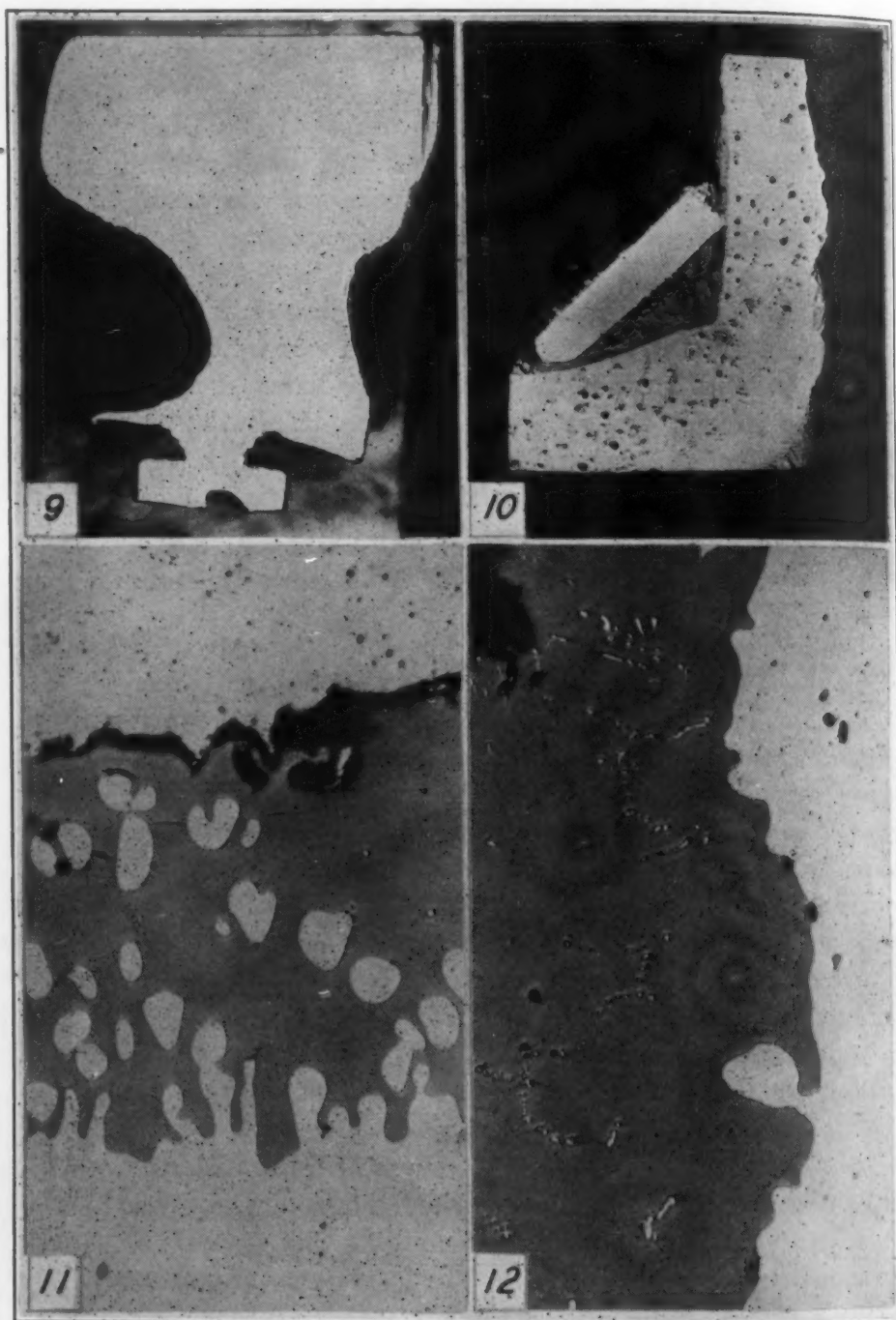
Fig. 9—Cross Section of Melt 0-1. The Hole Has Welded up in a Perfect Manner. Enlarged × 2. Fig. 10—Section Through Melt 0-3 Showing Part of the Ingot Iron Crucible, a Piece of Electrolytic Iron, and Fused Iron Oxide in Between the Two. Enlarged × 2. Fig. 11—Interpenetration of Oxide and Iron in Melt 0-3. Note the Numerous Fine Oxide Globules Near the Boundary of Oxide and Electrolytic Iron (Upper Boundary). × 100 Fig. 12—Melt 0-3. Islands of Iron in Iron Oxide. × 100.

too small (less than 0.005 millimeter in maximum diameter) to permit any tests except etching tests to be performed. They were found to survive as long as the oxide, in which they were embedded, survived. No definite conclusions about their nature could be made on the basis of this evidence alone. Examination of a large number of such crystals suggested, however, definitely their octahedral symmetry, and this combined with their color, association and resistance to reagents, led the author to believe that he was dealing with inclusions of magnetite, the existence of which had not been known heretofore.

The association of these inclusions with ferrous oxide is natural. Indeed, as was shown by Chaudron (13) and Eastman (29) ferrous oxide prepared at high temperatures becomes unstable on cooling and decomposes, in part, according to the reaction:

$$4FeO = Fe_2O_4 + Fe$$
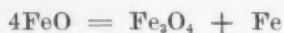
Some Fe_3O_4 is soluble in FeO as was shown by Matsubara (42); but if there be an excess over this amount it should crystallize out, provided opportunity for such crystallization is given. Apparently such opportunity is not given in the ordinary case of ferrous oxide inclusions, or else the solubility limits of Fe_3O_4 are not exceeded, because no traces of these "magnetite" crystals could be found in the artificially prepared FeO inclusions.

The possibility of the crystals being a compound other than Fe_3O_4, a complex compound, perhaps made up of elements other than iron and oxygen, must, of course, also be kept in mind.

The melt O-3 was made in order to gain further insight into this matter and, at the same time, to obtain larger areas of ferrous oxide for metallographic testing, a crucible was machined from ingot iron, charged with pieces of electrolytic iron and a considerable amount of Fe_2O_3, and heated to 1400 degrees Cent. in vacuo.

Fig. 10 shows a section near the bottom of the crucible which was chosen for examination. The diagonally reposing piece is electrolytic iron and the gray material, in the corner, between this piece and the walls of the crucible, the oxide.

The interpenetration of the oxide and the iron is shown by Figs. 11, 12 and 13. Of especial interest are the rounded oxide inclusions which have formed in the electrolytic iron in an area adjoining the oxide mass (upper portion of Fig. 11, right portion of Fig. 12).

Is FeO Dissolved by Iron at 1200-1400° C?—Their existence would tend to imply that FeO was actually dissolved by the iron at 2550 degrees Fahr. (1400 degrees Cent.) and precipitated from it, on cooling, in the form of these rounded particles. Similar observations were made by A. McCance (37) who heated mild steel in contact with crushed mill scale at 2190 degrees Fahr. (1200 degrees Cent.) for 8 to 12 hours. Whiteley (37), in discussing McCance's paper, states that he also obtained interpenetration of iron and its oxide on long heating at elevated temperatures; he attributes this, however, to a penetration along grain boundaries rather than the solubility of the oxide in iron.

Just why the oxide should migrate along grain boundaries is not obvious—unless, indeed, these boundaries are small cracks—; it is equally obscure why the oxide penetrating along such "cracks" should deposit in the form of tiny spheroids rather than in the form of a continuous mass such as is actually observed in the oxidized cracks of annealed material. On the other hand, it is not easy to agree that FeO, at 2190 degrees Fahr. (1200 degrees Cent.), is soluble in solid iron to the extent suggested by the rounded oxides.

Are we not dealing here with a chemical reaction, taking place between solid substances, rather than solubility? Is not the formation of the small oxide islands but a preliminary stage of complete oxidation, such as is pictured in Fig. 12, where only few microscopic islands of iron have remained intact? Oxidation by solid oxide is effected, without doubt, through the medium of "solubility of the oxide in the metal," but the size of the resulting islands of oxide is no more a measure of this solubility than the ratio of oxide to metal in Fig. 13.

What Causes the Formation of "Magnetite" Inclusions? The entire line of contact between the electrolytic iron and the oxide was searched for magnetite-bearing inclusions, but in vain. A number of them were found, however, on the line between the ingot iron and the oxide. Fig. 15 illustrates such an inclusion. Its size definitely assures us that it was not present originally in the ingot iron, and its formation in the ingot iron region implies the existence in ingot iron of something that is absent in electrolytic iron and that is essential for the formation of this type of inclusion. What could this something be? It happens to be the 0.02
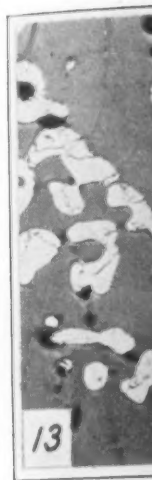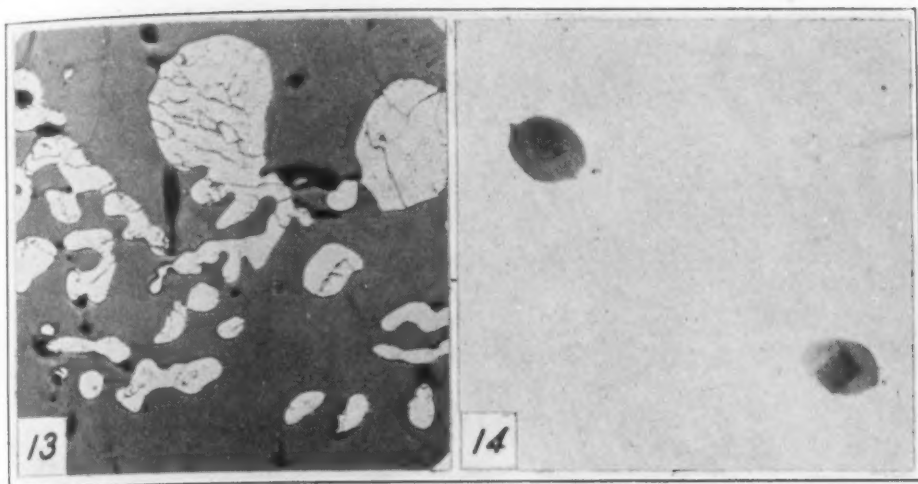
Fig. 13—Melt 0-3. The Oxide and Islands of Iron After Etching for 1½ Minutes with
10 per cent HNO₃. × 100. Fig. 14—Ingot Iron. Oxide Inclusions with Crystals. × 1250.

per cent sulphur, as will be shown in the chapter on oxide-sulphide
inclusions (Chapter IV). Just how the sulphur accomplishes the
release from the FeO of the hypothetical magnetite is not quite
clear. It appears, however, that iron sulphide is soluble to some
extent in iron oxide, and that, in the presence of dissolved sul-
phide, magnetite is not retained by FeO.

4. Manganese Oxide Inclusions

Melt 0-4 was next made when attention was devoted to man-
ganese oxide inclusions. Chemically pure Mn_2O_3 was charged in
the electrolytic container and melted in air in order to avoid any
loss of oxide, and additional Mn_2O_3 was dropped in the form of
pellets on the molten metal which absorbed them readily. It was
expected that the excess oxygen of Mn_2O_3 would oxidize some of
the iron according to the equation:

$$Mn_2O_3 + Fe = 2 MnO + FeO$$
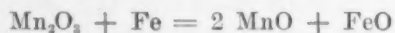
Some FeO inclusions would then result alongside of inclusions
of MnO (provided such inclusions exist) and opportunity would
be had to examine the two oxides side by side and to compare their
characteristics and properties.

Fig. 17 gives a general view of the inclusions which were found
to have developed and which were observed to be more or less
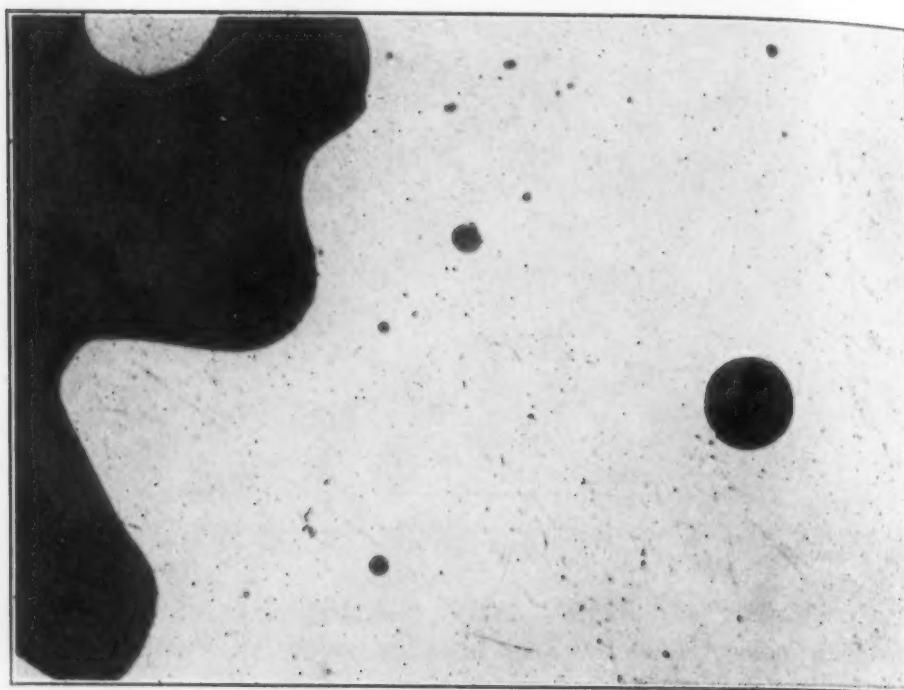uniformly distributed throughout the ingot. These inclusions re-

Fig. 15—Melt 0-3. An Artificial Crystal Bearing Oxide Inclusion Developed in Ingot Iron. × 500.

semble very closely iron oxide inclusions, but appear to the trained eye a shade darker.

Fig. 18 is representative of the appearance of the inclusions at × 500. They all look alike and appear to be homogeneous throughout. Are some of them FeO and some MnO? Or are they all solid solutions of FeO and MnO? Let us examine the experimental evidence.

Sulphur printing for 20 seconds had but little effect on pure iron oxide inclusions. In the present case all inclusions were dissolved by this treatment (compare Figs. 18 and 19). None of the inclusions are therefore iron oxide.   We repolish the specimen, select another group of representative inclusions (Fig. 20) and proceed to apply the Campbell and Comstock method for their identification. Etching for 10 seconds with 10 per cent nitric acid induced some pits and irregularities to appear in the inclusions (Fig. 21) which, however, are not very serious. Chromic acid is without effect.   Boiling sodium picrate slightly emphasizes the etching marks left by the nitric acid. 10 per cent boiling potassium

hydroxide induces no change (Fig. 22) ; finally, a saturated solution of stannous chloride disposes of all inclusions (Fig. 23).

According to Comstock, then, the inclusions are primarily iron oxide, and we just convinced ourselves, by the sulphur printing test, that they were not iron oxide. MnO, according to Comstock, should have been attacked by boiling sodium picrate. Yet, in the present case, the effect of this reagent was barely more pronounced than that of nitric acid.

The answer, of course, is that the inclusions are neither iron oxide nor manganese oxide but a solid solution or intimate mixture of the two.[18] It will be seen later that ferrous oxide, although resistant to acids when pure, becomes susceptible to their attack when contaminated with sulphide. The presence of MnO (and, perhaps, of other oxides as well) seems to have an analogous effect. We were dealing, heretofore, with the inclusions en masse.

Applying high magnifications and searching patiently for evidences of heterogeneity, a number of inclusions were discovered (melt 0-4) portions of which exhibited a complex structure. It must be noted, however, that the proportion of the complex constituent in these inclusions was small in every case.

Figs. 24 and 25 illustrate the appearance of these inclusions at $\times$ 2500. The main body of the inclusions consists of the uniform gray FeO-MnO solid solution, while at the rim a constituent of lighter gray (suggesting FeO) is seen, always accompanied by an almost equal proportion of a very dark material (most likely an oxide-rich in MnO).

In order to check the observations just made and, at the same time, to observe the effect of a greater relative proportion of iron oxide, another melt (0-5) was prepared with a mixture of equal parts of Mn_2O_3 and Fe_2O_3 as the inclusion material.

The resulting inclusions had exactly the same appearance as the inclusions of 0-4 and gave essentially the same reactions. The effects of the nitric acid and boiling sodium picrate etches were

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[18]Another instance of apparently homogeneous FeO-MnO inclusions was observed when a pure iron-manganese alloy (8 per cent Mn) was annealed at a high temperature. Fig. 26 shows the appearance of the etched surface near a series of blowholes along which oxidation penetrated deeply. It is seen that the metal surrounding the holes is etched less deeply than the normal alloy. The depth of etch is a function of the manganese content and it is obvious that some manganese was removed from the metal near the holes, having been oxidized in preference to iron. The alloy is "demanganized" near the holes, as it were, much in the same way as steel is decarburized. While CO is volatile however, MnO is not and so the medium gray oxide masses seen in some of the holes (from the others they were removed by careless polishing) must contain both the MnO and FeO. Yet they are perfectly uniform and exhibit no indications whatever of a duplex structure.
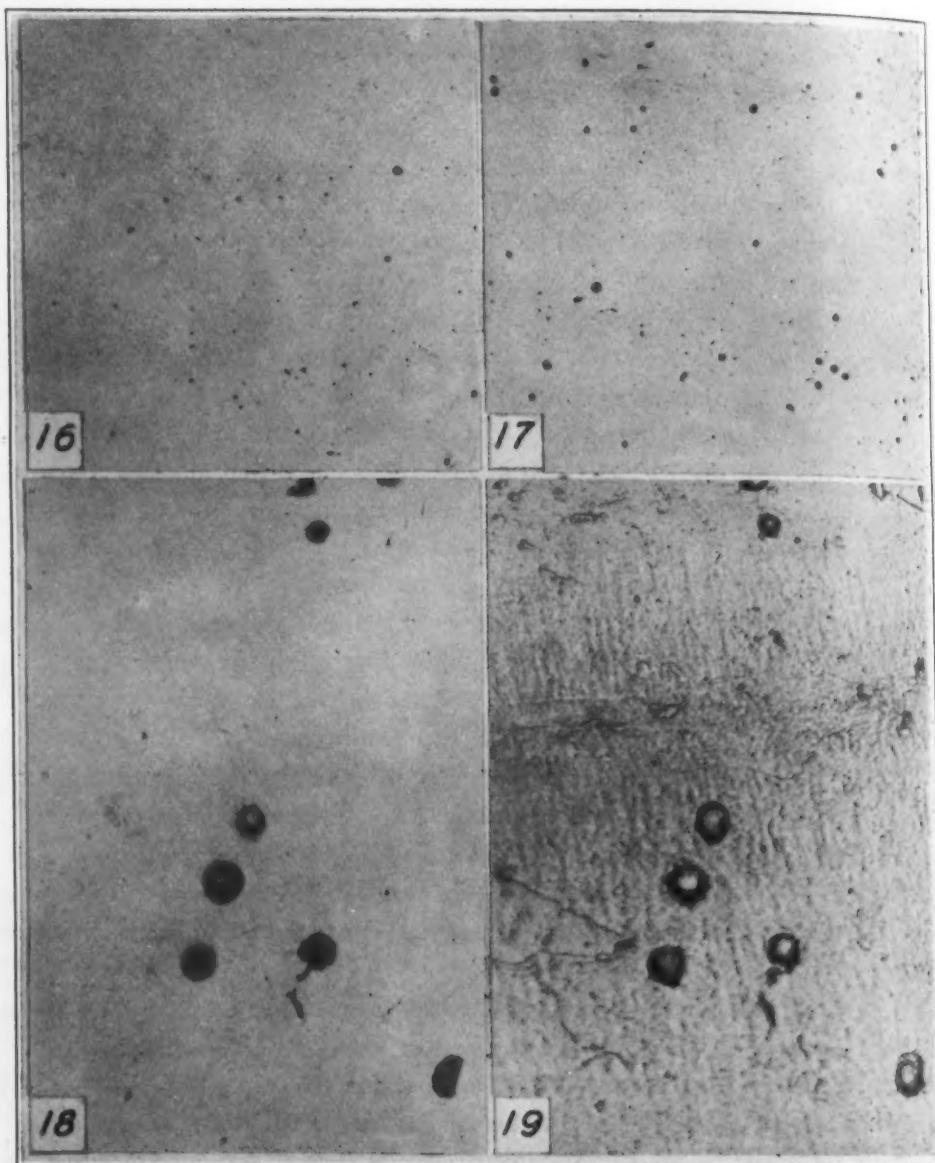
Fig. 16—Melt 0-2. Pure Iron Oxide Inclusions in Iron. × 100. Fig. 17—Melt 0-4. Appearance of "Mixed" FeO-MnO Inclusions. × 100. Fig. 18—Melt 0-4. A Group of "Mixed" FeO-MnO Inclusions at × 500. Fig. 19—Melt 0-4. Same as Fig. 18 After Etching by 20 Seconds Sulphur Printing. All Inclusions are Destroyed. × 500.

much less pronounced, however, showing that the resisting power of FeO-MnO inclusions increased with the decrease in relative MnO content.

The readiness with which manganese, in the presence of oxygen, leaves the metal bath is brought out by a comparison of the
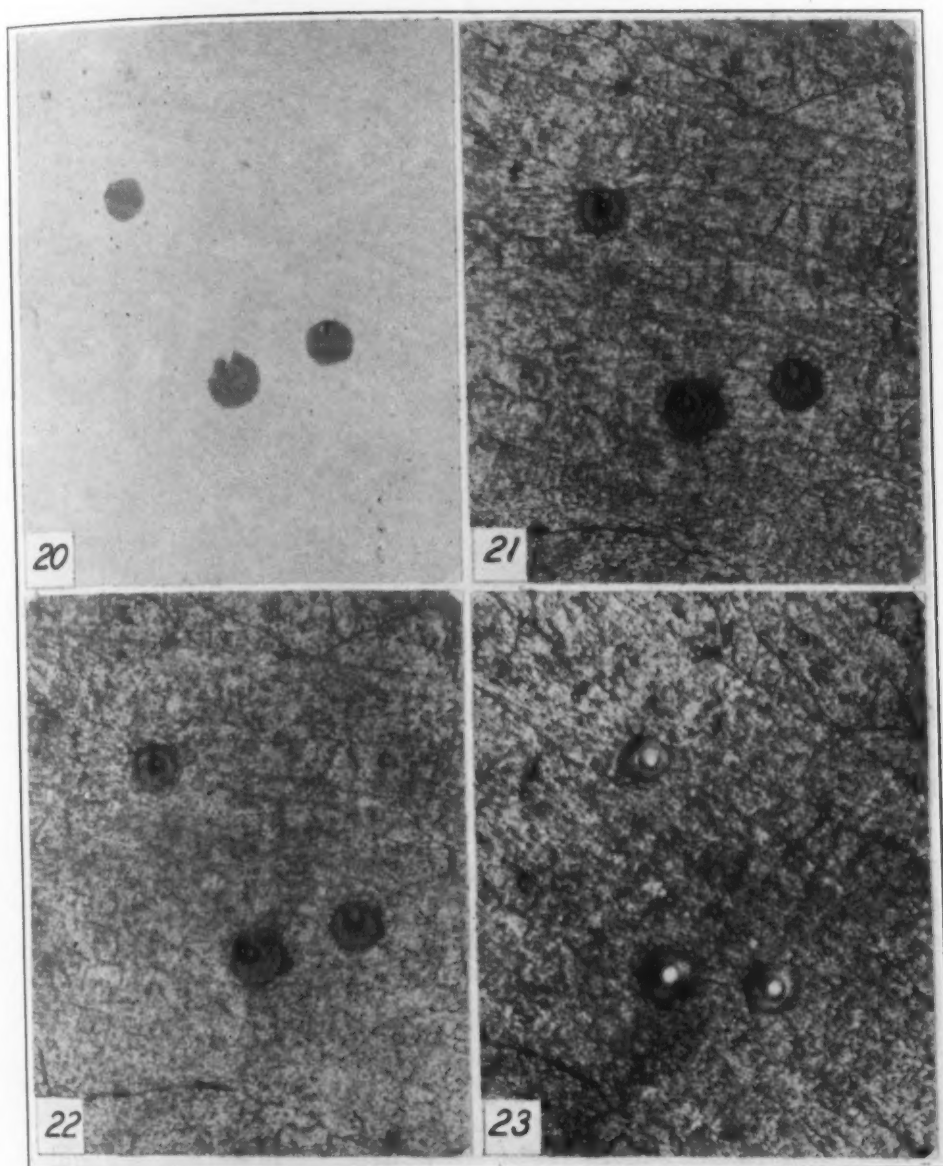
Fig. 20—A Selected Spot. $\times$ 500. Fig. 21—Same as Fig. 20 After 10 Seconds Etching with 10 Per Cent HNO$_3$. $\times$ 500. Fig. 22—Same After 10 Minutes Etching with Boiling 10 Per Cent KOH. $\times$ 500. Fig. 23—Same After Etching 10 Minutes with a Saturated Solution of Stannous Chloride in Alcohol. $\times$ 500.

percentage found by analysis and the percentage charged. 4.85 per cent manganese was delivered into the melt 0-4, and only 0.3 per cent manganese was found to be present in the ingot. Out of 2.14 per cent manganese charged into melt 0-5 only 0.087 per cent manganese was preserved. Yet no manganese-rich oxide layer had
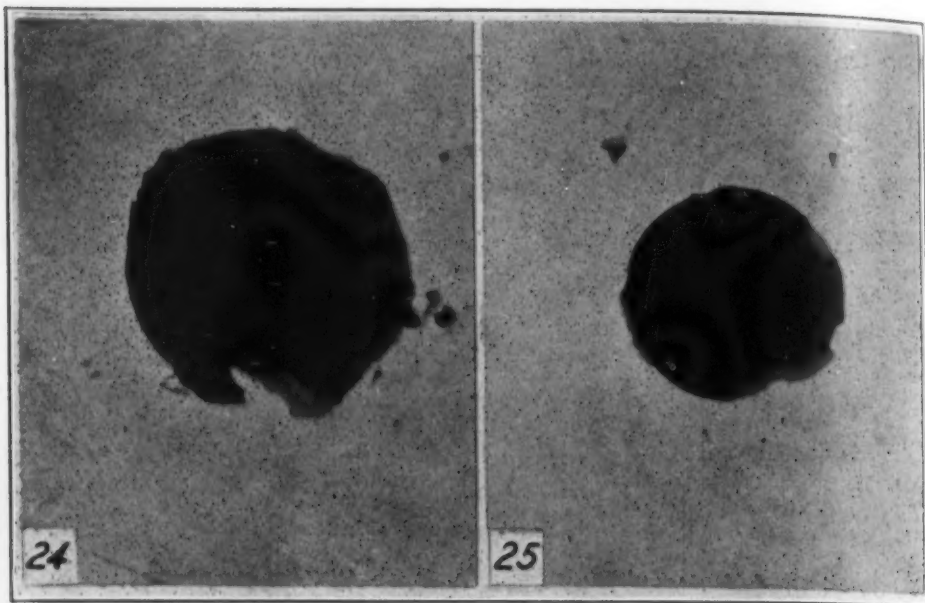
Figs. 24 and 25—Complex Inclusions in Melt 0-4. Note the Roughly Equal Proportion of Light and Dark Constituent Appearing at the Rim of the Inclusions. × 200.

formed on the top of the melt in either case. The walls of the crucibles were, however, discolored suggesting that the oxide had been absorbed by the relatively porous alundum.

The Constitution of "Manganese Oxide" Inclusions. From the observations just made it appears that MnO as such does not exist as separate inclusions in iron, barring individual, quite exceptional, or accidental inclusions. The question arises whether we had good reason to expect such inclusions to exist. The reaction

$$Mn + FeO = MnO + Fe$$

is known to be reversible; it is equally well-known that manganese is incapable of "deoxidizing" iron completely "no matter how much manganese is added" (McCance, 37). Any manganese added to molten iron distributes itself between the iron and the oxide in a manner governed by the concentration of the factors involved, and the temperature. That some manganese was actually reduced and passed into the iron, in the case of the melt 0-4, could be inferred from the relative readiness with which this metal was discolored on etching. The presence of MnO, then, necessarily implies the presence of FeO. The reverse is, of course, also true; i. e., if manganese be present in iron, the existence of FeO in the metal will imply the presence in it of MnO. Analyses of "oxide

inclusions'' made by a number of investigators substantiate this deduction.

Analyses of Oxide Inclusions[19]

FeO	MnO	Observer
24.7	66.0	Ruhfus
23.1	71.0	Ruhfus
26.1	64.0	Goerens
20.4	63.1	Hibbard
28.3	66.2	McCance

The next question is: how will these two oxides react with each other? They are similar in their chemical characteristics, possess the same crystal symmetry (cubic) and crystal structure (NaCl type). It is difficult to see how they could avoid being soluble in each other, at least to a limited extent.

Photomicrographic evidence obtained by the writer points toward the existence of such solutions between FeO and MnO. Nor is this the only evidence. M. Matveieff, in 1910, (43) prepared "manganese oxide" inclusions by forging a wrought iron tube charged with Mn_3O_4 and heated to 2370 degrees Fahr. (1300 degrees Cent.). Matveieff's inclusions having never been in molten iron are not representative of true inclusions, to be sure; his observations, nevertheless, are of great value. Matveieff found the oxide to have agglomerated to a gray homogeneous mass interrupted by a network of a black constituent. The gray material gave indications of the presence of manganese, which was reduced by hydrogen, and was interpreted to be a solid solution of the oxides, rich in FeO. The black constituent was unaffected by hydrogen and was thought to be a solution rich in MnO.

In a later paper on similarly prepared inclusions (43), Matveieff revised his former descriptions and referred to the "black" constituent as a "brown" solid solution rich in MnO, and to the gray constituent as a eutectic between pure FeO and this "brown" solid solution.

The exact constitution of the FeO-MnO inclusions will be known definitely only when the equilibrium diagram of the system FeO-MnO is worked out. For the present it must be born in mind that the existence of solid solutions between FeO and MnO
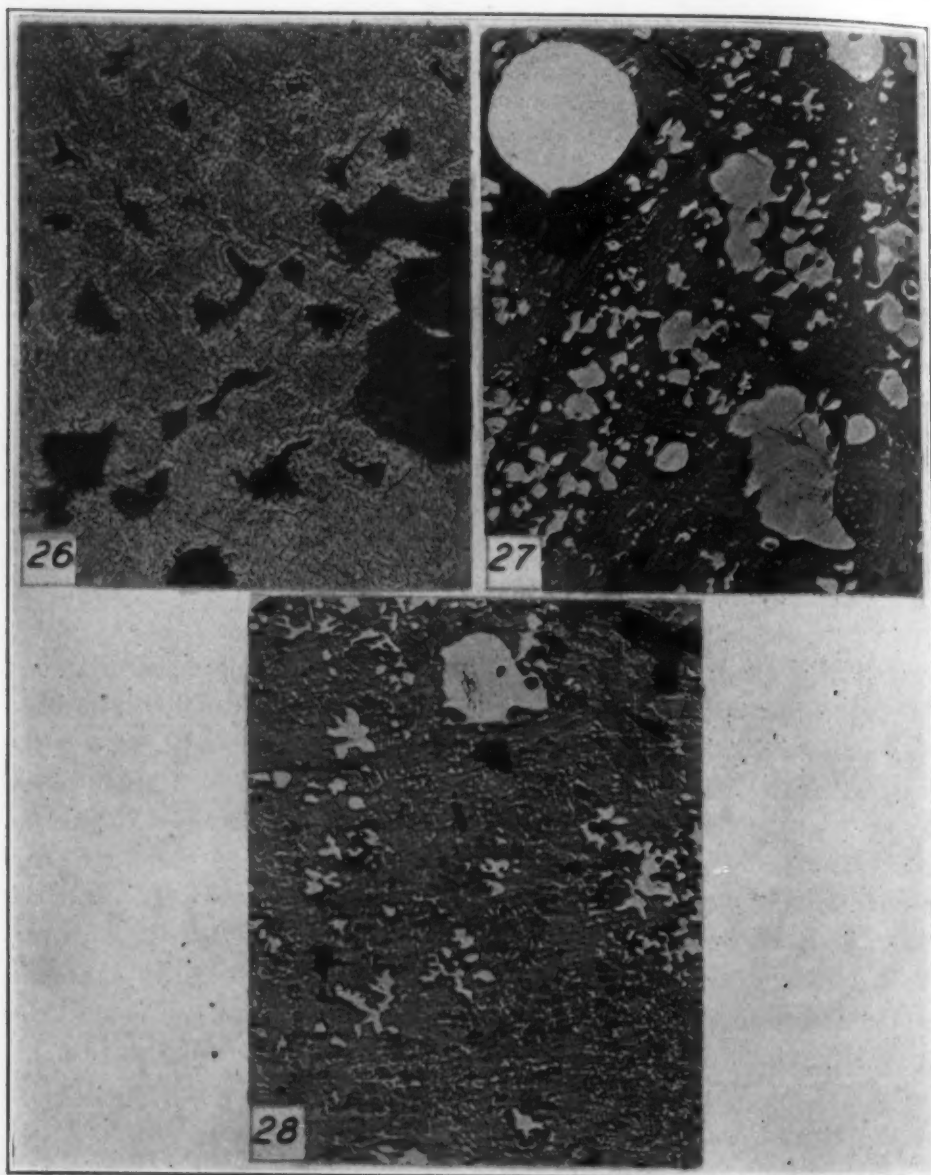
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[19]Collected by McCance.

Fig. 26—Alloy of Pure Iron and Manganese (Manganese 8 Per Cent). Annealed and Etched with Dilute Nitric Acid. Note the Development of Uniform Gray Oxide and the "Demanganization" Around the Blow Holes. × 100 Fig. 27—Ingot Iron Ladle Slag. Ferrous Oxide and Complex Silicates. Note the Iron Globule. × 100. Fig. 28—Ingot Iron Ladle Slag. Another Spot. × 100. Fig. 28—Ingot Iron Ladle Slag. Another Spot. × 100.

is clearly indicated, and that the occurrence of pure MnO inclusions is unlikely.

5. Alumina Inclusions

Before leaving the discussion of oxide inclusions a brief reference to alumina and silicate inclusions will be made although no

direct experiments concerning these inclusions were undertaken.

Description. Alumina inclusions were obtained by the writer when he prepared an artificial "ingot iron" (melting rusty sulphur-bearing electrolytic iron in an electric crucible furnace) and attempted to deoxidize the melt, just before pouring, with aluminum. On polishing the longitudinal section of rod forged from this material, elongated streaks of a hard substance were seen to be brought out in relief on the polished surface. Fig. 29 shows the appearance of these streaks at $\times$ 100. It corresponds in all details to the excellent description of alumina inclusions given by F. Comstock (48).

The streaks consist of an aggregate of hard, blackish particles which are slightly rounded in outline. They have not been elongated by forging. The hardness of alumina causes the inclusions to stand out in relief, after preliminary polishing; and unless great care is exercised, they are easily dragged out of the section in subsequent polishing operations. The infusibility of alumina accounts (as was pointed out already by Comstock for the small size of the particles and their failure to coalesce; and both the hardness and infusibility explain why alumina does not elongate on rolling.

An explanation for the elongation and segregation of a group of alumina inclusions into streaks has not been given, as far as the author is aware; this phenomenon is, however, merely an illustration of the behavior, on deformation, of any aggregate consisting of small, hard particles dispersed through a plastic matrix.

Fig. 30 shows a portion of the streak at $\times$ 2500. The irregularity of the alumina particles is worthy of note. This irregularity in outline is further illustrated by Figs. 31 and 32, which show complex inclusions of alumina, iron oxide, and a sulphide-oxide eutectic. Such inclusions are formed where the amount of aluminum was insufficient to take care of all the oxygen.

Fig. 31 is illustrative of the case of only a slight deficiency in aluminum. The main dark portion of the inclusion is either alumina or iron aluminate; the small light gray protuberance in the right lower portion is FeO which is associated with a still lighter constituent, (indicated by the arrow), the FeO-FeS eutectic.

Fig. 32 shows no free iron oxide. In this inclusion a dark
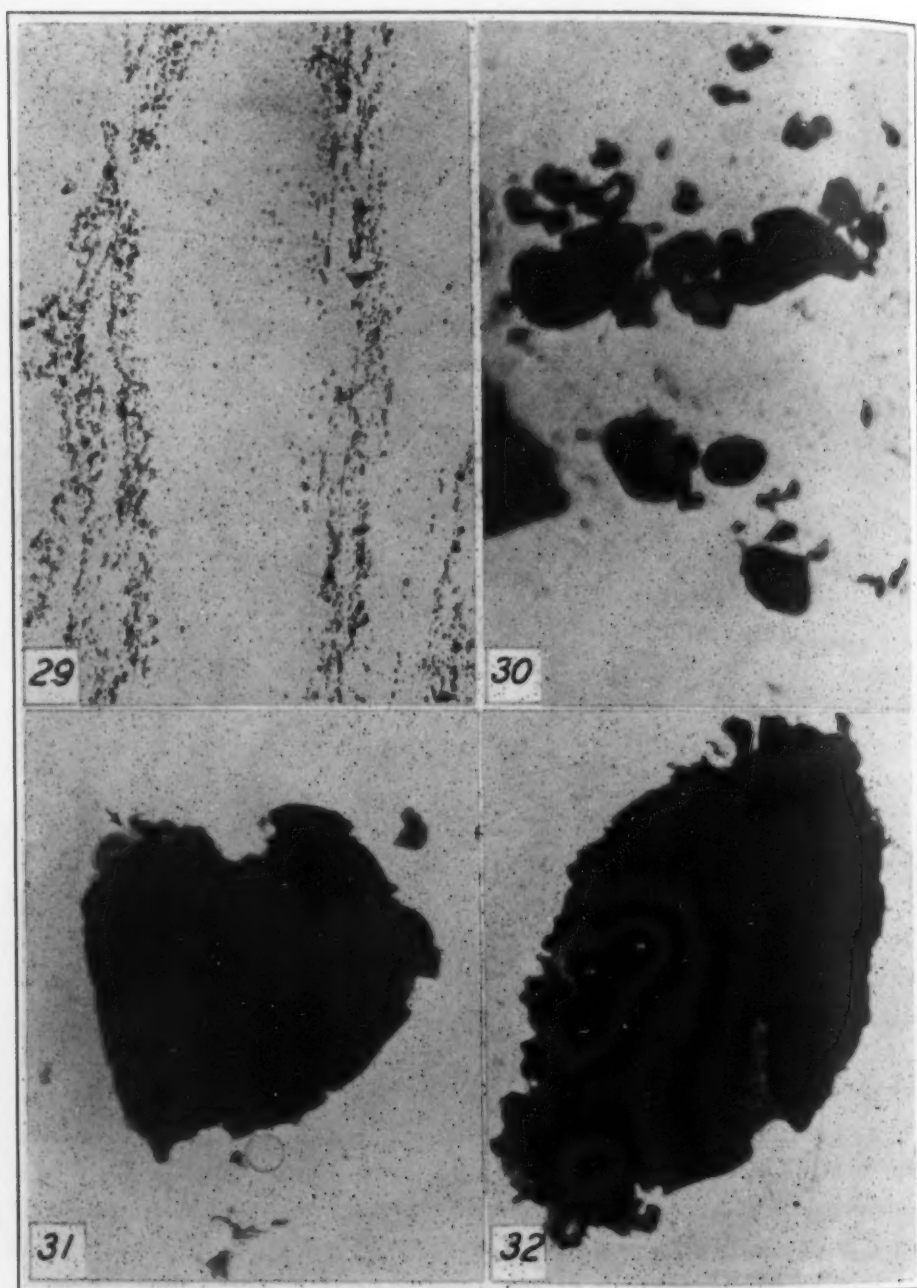
Fig. 29—Typical Streaks in an Iron Melt Deoxidized with Aluminum. $\times$ 100. Fig. 30—Portion of the Streak of Fig. 29. $\times$ 250. Fig. 31—A Complex Inclusion. The Main Part of it is Alumina or an Aluminate of Iron. The Lighter Gray (Bottom Right Corner) is FeO Associated with Some FeS. $\times$ 2500. Fig. 32—Another Complex Al$_2$O$_3$-FeO-FeS Inclusion. Note the Dark Gray Center Part, the Black Rim on the Right and the FeO-FeS Eutectic in a Crevasse and at the Lower Rim. Note Also the Irregularity in Details of the Outline of this Inclusion. $\times$ 2500.

compound intermediate in color between alumina and iron oxide
is predominant; perhaps iron aluminate (or a solid solution of
FeO in iron aluminate, for all we know); this is bounded by a
darker rim suggestive of greater alumina content; finally the FeO-
FeS eutectic is seen to be lodged in cavities on both sides of the
inclusion, and in the form of a narrow envelop at the bottom.

Complexity of Oxide Inclusions. These photomicrographs are
submitted as evidence of the complexity of oxide inclusions, even
in so extreme a case as that of alumina whose high heat of forma-
tion, infusibility, chemical inertness and insolubility in iron would
appear to guarantee its immunity from contamination.

We may safely conclude, in the absence of experimental evi-
dence to the contrary, that pure FeO inclusions can form only in
pure iron or in pure iron-carbon alloys. In the presence of other
elements, introduced intentionally or present as impurities, iron
oxide will always be contaminated by the oxides of these elements.
Thus an oxide inclusion in an iron-manganese-nickel alloy, for
example, will be a complex (solid solution or aggregate of solid
solutions) of iron, manganese and nickel oxides whose relative
proportions will be governed by the equilibrium relations existing
in the metal bath, in the neighborhood of the inclusion, at the
instant of its formation.

This applies, of course, not only to the oxides. It will be
seen, in the chapter on oxide-sulphide inclusions, that sulphides,
in the presence of oxides, will invariably be associated with the
oxides, and even dissolve in them to a limited extent.

The oxide of silicon is no exception either—it merely happens
that we are accustomed to designate complexes of the more basic
oxides with silica as silicates rather than as complex oxides.

6. Silicates in Iron

Sources and Formation. Silicates are formed on the inter-
action of basic oxides, such as FeO and MnO, with the oxide of
silicon, SiO_2, as is well known. Silicon as such is introduced into
steel through the pig iron, and is oxidized to SiO_2 by the same
agencies that yield the basic oxides, i. e., the iron ore and the
oxidizing blast or furnace gases. In addition, silica and silicates
are present in the furnace walls, ladle lining, etc. The slag formed
in steel making consists essentially of silicates.

Silicate inclusions, broadly speaking, can originate in three distinct ways, namely, from

(1) Mechanically entrapped fragments of the brickwork and lining
(2) Mechanically entrapped slag particles
(3) Reaction products of the bath.

In the author's opinion the first two possibilities have been largely over-emphasized. There is little opportunity given for the slag from the blanket to become entangled in liquid iron; it is equally unlikely that fragments of the brickwork should disperse themselves in a more or less uniform manner through the metal bath. Such silicate inclusions as are found in iron and steel, (barring exceptional inclusions), must have originated in a manner quite analogous to that of other oxide inclusions.

The formation of silicate inclusions as reaction products does not necessarily imply any marked solubility of silicates in molten iron, although contrary to accepted notions, a slight solubility is indicated. As pointed out by McCance (37), who holds silicates to be insoluble in iron, the formation of silicate inclusions can be depicted as follows:

(1) The FeO of the slag oxidizes the carbon of the bath and eliminates itself thereby gradually
(2) As the concentration of FeO in the slag falls SiO_2 begins to oxidize the carbon, metallic silicon being formed which passes into the bath
(3) The slag becomes viscous and, to restore its fluidity ore is added which increases the concentration of FeO which, in turn, resumes its oxidizing functions. This causes a re-oxidation of the silicon in the bath resulting in the precipitation of the insoluble silica "as a cloud of minute inclusions throughout the bath"
(4) "Any silicate particles so produced will be attacked by metallic manganese to form manganese silicate."

This description depicts, probably, quite correctly the formation of many silicate inclusions. It is equally probable, however, that it does not tell the whole story.

Solubility of Silicates in Molten Iron. In particular, the generally accepted view of the complete insolubility of silicates in molten iron is open to doubt. In order to gain some information

on this point and, at the same time, to see whether "a cloud of minute inclusions" will form throughout the metal bath in the absence of the mechanism given by McCance, two melts of the electrolytic iron and of silicates of iron and manganese (C. P.) were prepared in the usual way (melts 0-6 and 0-7). The resulting ingots were both found to contain tiny rounded inclusions not unlike those of the oxide melts; the inclusions, here, appearing merely much darker. Now, the melting points of the various manganese silicates are in the neighborhood of 2370 degrees Fahr. (1300 degrees Cent.), and those of the iron silicates (with the exception of Gruenerite, perhaps) are also below the melting point of iron. Ample opportunity was given for the silicates to agglomerate and to fuse in the electrolytic container before the collapse of the latter. If completely immiscible with, and insoluble in the iron, the agglomerated silicates would then be expected to float bodily to the top of the melt upon fusion of the container. Instead they were found to be dispersed throughout the melt as tiny rounded particles.

Must we not conclude that molten iron, at high temperatures, is capable of dissolving, partly, some silicates? Or at least, that molten iron is capable of being "silicatized" in the same manner as solid iron is capable of being oxidized at elevated temperatures. It is difficult, of course, to draw definite conclusions on the basis of one or two experiments; the results, nevertheless, are worthy of consideration.

The chemical analyses of the melts do not give reliable information, unfortunately. Silicates are practically insoluble in the reagents employed for analysis; they may, nevertheless have been attacked partly, and may have furnished thereby the 0.056 per cent silicon which was found in the melt 0-6 and the 0.02 per cent silicon and 0.05 per cent manganese found in 0-7. But it is not unlikely that a portion at least of the manganese and of the silicon found was present in the iron in the metallic state, the molten iron actually having reduced the silicon and the manganese from the silicate.

It will be safe to admit that the fundamental factors of concentration and of temperature are just as important in determining the course of silicate-metal reactions as the course of any other reactions. And that, therefore, in the case of silicates, just like

in the case of oxides, inclusions will form, the composition of which is governed by the concentration of the elements present and the temperature.

We must not forget, of course, that the composition of the metal bath is a function of the composition of the slag and that, with changes in the slag, changes in the metal phase will also take place. These changes, in many instances, may cause the formation of suspended inclusion droplets already in the molten iron. This applies to the case of oxide inclusions in general.

Constitution of Silicate Inclusions. Having gained some insight into the process of formation of silicate inclusions, the next question that presents itself is whether we are justified in drawing a rigid line of demarcation between iron silicate and manganese silicate inclusions, such as is drawn, for example, by Campbell and Comstock in their "Method for Identification." We found that there was no basis for such a division in the case of simple oxides. It is fairly evident that there is still less justification for such a division in the case of silicates which are known to occur naturally in a variety of forms in which MnO replaces FeO isomorphously.

Let us examine, however, the experimental evidence. Fig. 33 shows two representative inclusions of the melt 0-7. They appear homogeneous despite the presence in them of both iron and manganese silicates. Nitric and chromic acids are without effect on these inclusions. Sulphur printing for 20 seconds induces no changes. Boiling sodium picrate attacks the majority of the inclusions although it fails to eliminate them (Fig. 34). Does this indicate the presence of MnO? Possibly. We next etch with 10 per cent boiling potassium hydroxide. No changes are indicated (Fig. 35). Hence there are no manganese silicates present, according to Comstock. Stannous chloride is also without effect, while hydrofluoric acid completely dissolves the inclusions (Fig. 36) which are thus identified as iron silicate (?). We do not know what the exact composition of the inclusions is. We can be certain, however, that they are complex iron-manganese silicates. Pure manganese silicate inclusions do, probably, occur but very rarely in pure iron for the same reasons that make the presence of pure MnO inclusions unlikely.

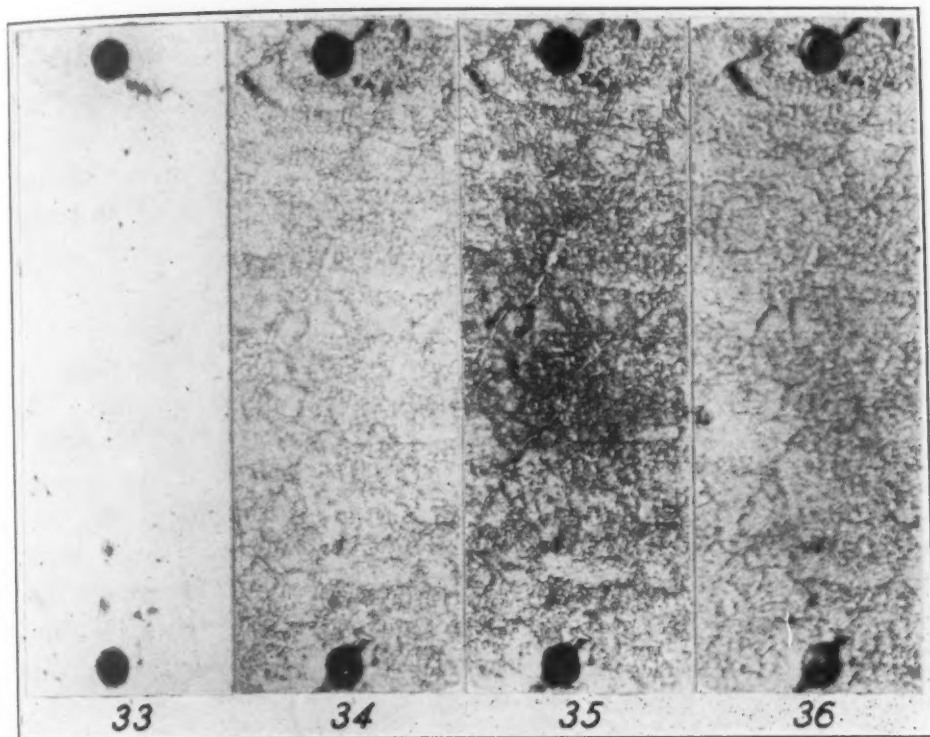In general, it can be said that, in the presence in iron of manganese, silicon and oxygen, iron-manganese silicates will form,

Fig. 33—Two Representative Inclusions.   × 100.   Fig. 34—Same After Etching for 10 Minutes with Boiling Sodium Picrate.   × 100.   Fig. 35—Same as Fig. 34 After Etching for 10 Minutes with Boiling 10-Per Cent KOH.   × 100.   Fig. 36—Same After Etching for 10 Minutes with a 20-Per Cent Aqueous Solution of Hydrofluoric Acid.   × 100.

associated with such excess oxides as are present. These silicates and oxides will form partial solid solutions, eutectics, etc., and among themselves and among each other, the exact constitution of the inclusions being governed, in each individual case, by the fundamental factors of concentration and temperature, applying to this case.

Photomicrographs of Silicate-Oxide Aggregates. Fig. 28 is a picture at × 100 of ingot iron ladle slag. The brilliant white islands appear, at first sight, to be included blobs of iron. This is, however, merely an illusion. We judge color and more especially brilliancy solely by contrast. In the presence of metallic iron the oxide of iron appears quite dull and gray, in the presence of a dark silicate it appears as brilliant and white as iron. The whitish islands are iron oxide. This becomes clear when we inspect Fig. 27, which shows the appearance of a real inclusion of metallic iron. The silicate groundmass appears, (in both pictures,) mottled, indicating the presence of several constituents. Higher magni-

fications reveal that the mottled appearance is due to the presence of a fine silicate-oxide eutectic (Fig. 37). The main mass of the silicate is fairly homogeneous in spite of the complexity of its composition.

Let us now consider another case, the case of some perfectly formed skeleton crystals of fayalite which were found in the brick-work of an open-hearth furnace. Fig. 38 serves to describe these crystals.

Perfection of crystal symmetry is no longer held to be a criterion of the purity of a mineral; one, nevertheless, would expect a perfect crystal to be less heterogeneous than a complex slag. The microstructure of the specimens tells another story. The differences in shade observed in the regular plates of Fig. 39 are unquestionably ascribable to a difference in orientation alone. Individual patches of a darker gray constituent different from the main mass, are however, observed here and there. Different eutectics which were found to be present in the specimen are illustrated by Figs. 40 and 41. Finally Fig. 42 shows a string of included typical magnetites.

We can learn from these observations that complex silicates can be homogeneous as well as heterogeneous, that they dissolve a considerable amount of iron oxide which may separate as a constituent of an eutectic or eutectoid; that, further, eutectics or eutectoids form among the silicates themselves, and that different classes of silicates form partial solid solutions among each other.

7. Summary

On the basis of fundamental physico-chemical data, the experiments of earlier investigators and the observations of the author the following conclusions can be drawn about oxide inclusions:

I. Sources. Oxides will invariably form in the presence of oxygen; the source of oxygen, in the Bessemer process, is the air blast, in open-hearth practice, the iron ore and furnace gases. The complex oxides known as silicates are also introduced from the brickwork of the furnace, the ladle lining, etc.

II. Formation. Iron oxide is soluble in molten iron and will be precipitated on solidification, in the form of oxide inclusions which will be the more numerous the higher the original oxygen content of the bath and the lower the carbon.

In the presence of manganese, or of any other oxide forming
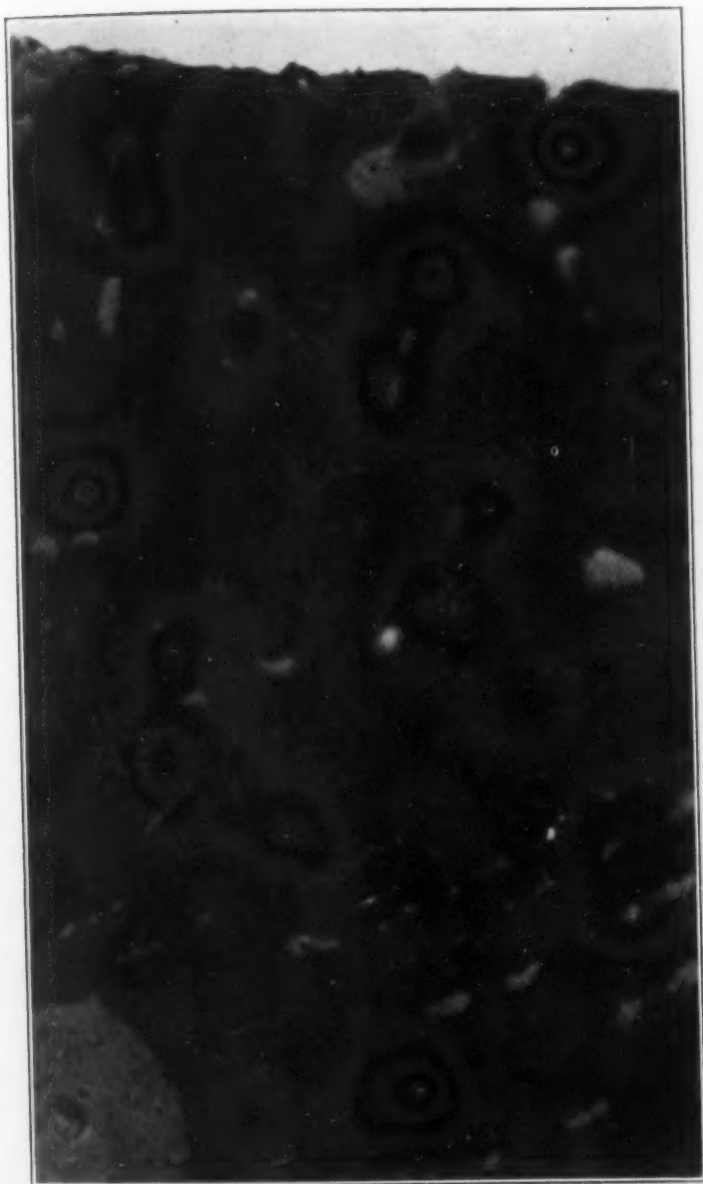
Fig. 37—Ingot Iron Ladle Slag. Ferrous Oxide in a Matrix of
Complex Silicate and Silicate-Oxide Eutectic. $\times$ 2500.

metals soluble in iron, oxides of these metals will form at the
expense of iron oxide, to an extent governed by the equilibrium
conditions existing in the metal bath.

If an oxide thus formed is largely insoluble in the molten
metal and opportunity is given for it to leave the bath, true
"deoxidation" of the bath is effected. Deoxidation by ferro-
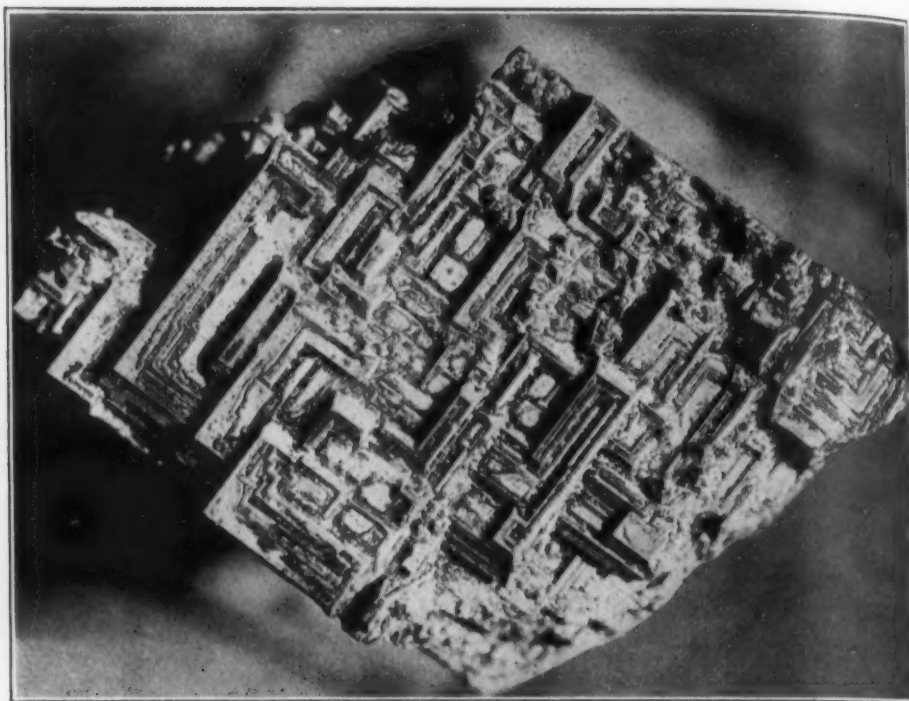
Fig. 38—General View of the Crystals. × 3½.

manganese is limited since manganese oxide is somewhat soluble in iron. Deoxidation by ferrosilicon is more complete since silica and silicates are soluble to a very small extent in iron.

Oxide (and silicate) inclusions form not only due to the precipitation of dissolved oxides at the instant of solidification of the metal, but also due to precipitation prior to solidification, whenever the changing composition of the metal and slag systems induces such precipitation.

III. Constitution. Pure iron oxide inclusions, at atmospheric temperature consist of a solid solution of Fe_3O_4 in FeO. In the presence of sulphides (in solid solution in FeO) Fe_3O_4 may be liberated in the form of magnetite crystals (?).

If manganese be present, the oxide inclusions will consist of a solid solution of iron and manganese oxide, or of an aggregate of such solid solutions, the constitution of each individual inclusion being a function of the equilibrium conditions prevailing in the metal bath, in the neighborhood of the inclusion, at the time of its formation. Pure MnO inclusions can occur only as individual, quite exceptional, inclusions in iron and steel.

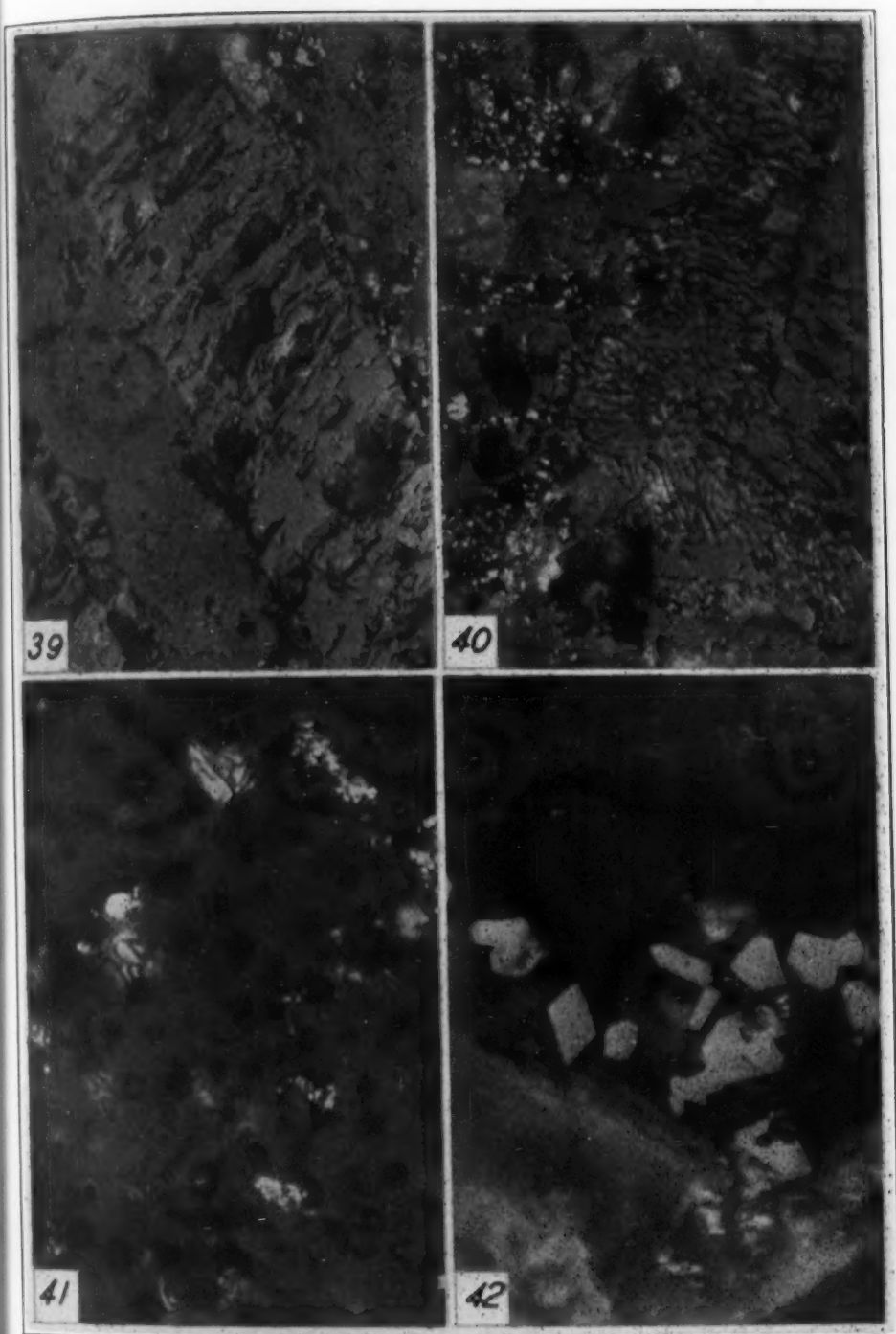Fig. 39—Bands of Twinned (?) Plates. Note the Presence of a Dark Gray Constituent and of Numerous Bright Spots. The Latter are Magnetite Crystals. × 500. Fig. 40—A Eutectic Within the Crystal. × 560. Fig. 41—Another Eutectic. × 2500. Fig. 42—Magnetite Crystals Within the Fayalite Crystal. × 2500.

In general, in the presence of foreign elements, oxides of these elements will be associated with iron oxide in a manner depending on the chemical relationship existing between them and iron oxide. In particular, in the presence of silicon, silicates will form, and free simple oxides are exceptional. It is unlikely that pure manganese silicate exists in iron and steel.

IV. Behavior. No evidence has been advanced which would show conclusively that oxide inclusions "migrate" in the metal after solidification. In the absence of such evidence it is postulated that oxide inclusions, under ordinary circumstances, remain where they were born.

Working at high temperatures (above 1100 degrees Cent.) elongates pure or relatively pure iron oxide inclusions; particles measuring below 0.005 millimeters in diameter are, generally, not elongated. The same applies to silicate inclusions which, however, appear to be elongated more easily than the oxides.

Little is known about the rolling characteristics of other complex oxides. Alumina is not elongated on hot working; it is however thrown into elongated streaks.

V. Appearance. Pure iron oxide inclusions are of a medium gray color and appear, in the cast metal, as small rounded particles (maximum diameter generally below 0.01 millimeter).

Iron-manganese oxide inclusions are similar to those of pure iron oxide, exhibiting, however, a darker shade of gray.

Silicates are distinctly gray or greenish-black and have a glossy, or greasy, appearance.

Magnetite inclusions are of a dark gray color and exhibit geometric forms suggestive of octahedral symmetry.

Alumina inclusions are almost black, exhibiting semi-angular, semi-rounded irregular forms, the detailed outlines of which are highly irregular. Their maximum diameter seldom exceeds 0.005 millimeters.

VI. Reactions. Pure iron oxide inclusions are very little affected by the action of 20 seconds sulphur printing, while MnO-bearing oxides are removed or pitted by this treatment. Sulphur printing has no effect on silicate inclusions.

Stannous chloride dissolves oxide inclusions, both in the absence and presence of MnO, and leaves silicates unchanged.

Boiling sodium picrate generally indicates the presence of

manganese oxide by lightly attacking the complex oxide. Its action is not decisive however.

Dilute hydrofluoric acid dissolves silicate inclusions.

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FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part XVIII[1]

By H. B. Knowlton

Abstract

*This article covers the solid carburizing materials,
the method of packing for carburizing, carburizing pro-
tection, the reuses of carburizing materials, carburizing
furnaces, carburizing containers, gas carburizing, and
methods of control of the depth of case. The action of
the base materials and the chemical energizers in car-
burizing compounds is explained. The importance of
uniformity of the compound is stressed. The value of
good well-sealed boxes is brought out. The general
types of furnaces and the practical methods of opera-
tion are described.*

Solid Carburizing Materials

THE chemistry of carburizing and the fundamental principles
governing the process have already been discussed, but the
materials used to produce carburization have been touched on
rather lightly. It may be well to devote some time to the discus-
sion of this very important phase of the subject.

All of the carburizing materials may be divided into three
general classes; solids, liquids and gases. The solid and the liquid
materials act by producing one or more carbonaceous gases which
diffuse into the steel and deposit carbon in a form which can be
dissolved by the hot steel. The solid materials will be considered
first.

[1]This is the eighteenth installment of this series of articles by H. B. Knowlton. The
several installments which have already appeared in Transactions are as follows: March, June
and October, 1925; January, April, May, June, August, October, December, 1926; March,
May, July, September, November, 1927; January, May, 1928.

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Society, is metallurgist of the Fort Wayne Works, International Harvester
Company, Fort Wayne, Ind.

The solid materials are used in the form of small granules. The steel and the carburizing material are packed in boxes, pots, or other containers so that each piece of steel is surrounded with the granules of the carburizing materials. As all of the solid materials used contain carbon, when they are heated to the carburizing temperature they burn to form carbon monoxide or carbon dioxide. The oxygen necessary to support this combustion is found in the air included in the spaces between the particles of the carburizing material. As there is only a small amount of air present there is only a partial burning of the carburizing material. Also since there is an excess of the carburizing material and only a small amount of air, the tendency is to produce carbon monoxide, which is a carburizing gas. Sometimes during the latter part of a long run there is an excess of air in the top portion of the pot. This favors the production of carbon dioxide which is a decarburizing gas, and may take carbon out of the steel. The carburizing and the decarburizing of steel takes place according to the reversible chemical equation:—

$$2\ CO \quad \rightleftarrows \quad CO_2 \quad + \quad C$$

Carbon Monoxide   Carbon Dioxide   plus   Carbon
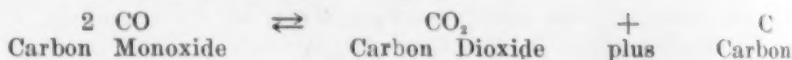
This reaction may go either direction depending upon the temperature, the pressure, the concentration of the gases in the box, and the carbon content in the surface layers of the steel. Other things being equal a condition which favors a concentration of CO in the box favors carburizing while a condition which favors the production of CO_2 tends to produce decarburization of the steel. With any given set of conditions there is a concentration of carbon in the steel which is in equilibrium with the system.

The speed of penetration of the carbon into the steel and the per cent of carbon in the outer layer increases with increase of temperature. Similarly increase of the pressure or the volume of carburizing gases coming into contact with the steel increases the speed of penetration and the concentration of carbon in the case.

Some of the solid carburizers in addition to burning to form carbon monoxide also decompose yielding some other gas which may or may not affect the carburizing action. This discussion will be limited principally to the solid carburizers and carbon monoxide and carbon dioxide. The action of other carbonaceous gases is similar in many respects to that of carbon monoxide.

REQUIREMENTS FOR A SOLID CARBURIZER

The following may be listed as some of the requirements for the ideal solid carburizer, based on the quality of work produced.

1. The material should produce the necessary amount of carbon monoxide gas (or other carburizing gas).
2. It should not favor the production of carbon dioxide.
3. It should produce a gradual case.
4. It should produce the desired per cent of carbon in the outer layer of the case. (Opinions differ somewhat as to what is the ideal per cent of carbon in the case).
5. It should produce uniform results.
6. It should not shrink unduly during use.

To these may be added another list of requirements based on costs.

7. It should produce a rapid penetration of carbon.
8. It should have a low cost per cubic foot.
9. It should have a low shrinkage by weight.
10. It should be capable of being used over and over with the addition of the minimum amount of new material.
11. It should not be injurious to the carburizing boxes or the steel carburized.

From the standpoint of the health and the comfort of the workmen, the following may be added.

12. The material should not be poisonous nor injurious to the workmen and should not be unduly dusty either as received or after use.

Some of these points are too obvious to warrant discussion while others may need a little expounding.

The statement that the carburizing material must produce uniform results infers that the material itself must be uniform. Some crudely mixed materials may not produce uniform carburization even on pieces in the same pot. A large shrinkage in use means a vacant space at the top of the box during the last part of the heat. If this space becomes filled with air there may be danger of decarburizing of the pieces in the top layer.

The cost per cubic foot is important. Carburizers are usually purchased by weight but they are used, by volume, that is it requires a certain number of cubic feet of material to fill a given number of boxes. The weight of the different carburizing mate-

rials varies from about 20 to about 50 pounds per cubic foot. Some materials not customarily used weigh even less than 20 pounds per cubic foot. Consequently in figuring the initial cost of a material it is necessary to consider the cost per pound and the weight per cubic foot.

It is entirely possible for a material to have a shrinkage by weight which is out of proportion to the shrinkage by volume. For example a material containing a great deal of moisture will lose considerable weight on heating. The amount of material which must be added after each heat depends upon a number of factors, among which may be mentioned the following—the shrinkage due to burning, the loss due to screening and handling, and the loss of strength of the material due to change of chemical composition or loss of important constituents.

It is claimed that some materials are injurious to carburizing boxes. Pitting of the steel is also sometimes due to the carburizing material. Materials which contain cyanides or ferrocyanides are poisonous, and consequently injurious to workmen. Fortunately these dangerous chemicals are not often used in solid carburizing materials. Many materials either are naturally dusty or become very dusty on use. These are offensive to the workmen.

SIMPLE SOLID CARBURIZERS

It might seem at first that any relatively pure form of solid carbon would make a good carburizing material but such is not the case. It must be remembered, however, that the carburizing does not depend upon the amount of solid carbon but upon the amount of carbonaceous gas produced.

Charcoal. Wood charcoal was probably the first material used to carburize the surface of solid iron or steel. While little is known positively concerning the manufacture of high carbon steel by the ancients, it is probable that it was done by heating wrought iron bars in a forge in contact with wood charcoal. Then the outer layers of the bars became carburized and consequently the steel formed could be hardened and tempered. In later centuries "blister" steel was manufactured by heating wrought iron bars in contact with wood charcoal.

Wood charcoal alone is not an ideal material for case carburizing. At the ordinary carburizing temperatures (1700 degrees Fahr. or lower) wood charcoal does not produce a very high

carbon case. It has a very high shrinkage the first time it is used, consequently there may be danger of decarburizing of the pieces near the top of the carburizing box. It has an advantage of a comparatively low price and a low weight per cubic foot. It is worth mentioning that there is a great deal of difference between the charcoals from different kinds of wood. In general the hard woods are heavier but do not shrink as much as the soft woods.

Sawdust. Sawdust is not much used as a carburizing material, but it is occasionally encountered. It is very light but has an extremely high shrinkage, which is a decided disadvantage.

Bone. Up until a comparatively few years ago bone and leather were among the most popular of the solid materials used for carburizing. Bone is a rapid carburizer and produces a high carbon case. It contains only a small per cent of carbon and cannot be used over again without the addition of a considerable per cent of new material. One of the common formulas a few years ago called for $\frac{1}{2}$ new bone, $\frac{1}{4}$ old bone and $\frac{1}{4}$ charcoal. When 50 per cent new material is added after each run, it is obvious that the cost of up keep of the material is high. In addition to this, bone is a relatively heavy material. Consequently the initial cost per cubic foot is comparatively high. There is probably a difference between the carburizing qualities of different kinds of bone. It is common to specify a certain kind of bone, for example shin bone. It is sometimes claimed that variable results are produced by an apparently uniform lot of bone. It is also claimed by some that there is enough phosphorus in bone to have a harmful influence upon the steel.

Leather. Leather is another organic material which has enjoyed some popularity as a carburizing material. Scrap leather may be prepared for such use by charring and then crushing to a suitable size. Leather is also a rapid carburizer producing a high carbon case. It is much lighter than bone but has a high shrinkage and requires the addition of considerable new to keep it up to strength. An objection has been raised by some that leather may contain sulphur which will have a harmful effect upon the steel. Some of the old formulas for compounds which would color the work as well as case harden it, called for mixtures of bone, leather, charcoal and sometimes cyanide. Leather is

not used as much as formerly partly on account of the price.

Other Organic Materials. All forms of organic material contain carbon and quite a number of them have been recommended at one time or another for carburizing. Hoofs and horns have been mentioned.

Among the vegetable forms of carbon which have been used may be mentioned the charcoal formed from nut shells and corn cobs. Their action in carburizing is probably similar to the other forms of charcoal although they have a different density, and shrinkage. Certain advantages have been claimed on this account.

Coal and Coke. Coal and coke are seldom used alone as carburizers. They are used, however, in some mixtures. They are comparatively heavy and slow burning. On the other hand they have a low shrinkage. There is a vast difference in the mechanical properties of different kinds of coke. Some are very friable and crush into dust quite easily while others are hard and strong. Both coal coke and oil coke are used in carburizing materials. The action of coke in conjunction with certain chemicals will be discussed later.

Carburizing Mixtures Containing Chemical Energizers

At the present time there are a number of carburizing "compounds" on the market which contain charcoal, coke or some other form of carbonaceous material and certain chemicals which are known as "energizers." These carburizing materials should properly be described as "mixtures" rather than "compounds," but the latter term is so commonly used that it may as well be employed here.

The chemical energizers generally used are the carbonates of the alkali and the alkali earth metals. The three which are used the most frequently are barium carbonate, calcium carbonate and sodium carbonate. Calcium carbonate is the same chemically as limestone and barium carbonate belongs to the same chemical family. Sodium carbonate is known as "soda ash" or "washing soda." The carbonates of magnesium, potassium, and other metals of the alkali and alkali earth groups could also be used, but for commercial reasons the three carbonates mentioned are the most common.

The action of the three chemical energizers are the same. These chemicals are never used alone but are always mixed with

charcoal, coke or some other form of carbon. When such mixtures are heated to the carburizing temperature the carbonates decompose giving off carbon dioxide gas according to the following chemical equation:

$$M\ CO_3 \quad \rightarrow \quad M\ O \quad + \quad CO_2$$
Metal carbonate plus heat forms Metal oxide plus carbon dioxide gas
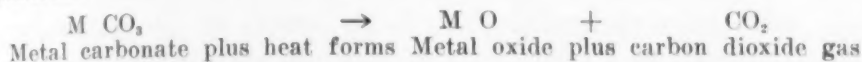
The carbon dioxide gas formed is not itself a carburizing gas, but on coming into contact with the excess of hot carbon particles (charcoal or coke) in the carburizing box, the carbon dioxide is converted into carbon monoxide gas according to the following equation:

$$CO_2 \quad + \quad C \quad \rightarrow \quad 2CO$$
Carbon dioxide plus carbon forms carbon monoxide gas
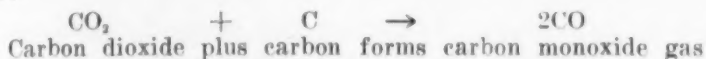
As has been stated before, carbon monoxide is a carburizing gas. As a small amount of chemical will liberate a large volume of gas, the addition of chemical to a carbonaceous material such as charcoal or coke greatly increases the amount of carbon monoxide gas which will be formed in the carburizing box.

One of the advantages of the use of these carbonates is that they are "regenerative." That is while they are decomposed by heat as shown by the previous equation, the metal oxides formed when exposed to air after cooling, absorb carbon dioxide from the air and are changed back to the original form. As it is sometimes stated they are "regenerated" on standing. It is possible that some of the chemical may be used up by combining with some other constituent in the compound. It is also possible that some of the chemical will be lost in handling.

There is some difference of opinion at the present time as to the quantity of the different chemicals which should be present in a carburizing compound. Some favor the use of a single chemical, but differ in their opinions as to which chemical it should be. Others believe that two or three of the chemicals should be present. Some have tried to figure out theoretically what the action of the different chemicals must be, based on the temperatures at which they are known to decompose. Unfortunately this theorizing sometimes leads to erroneous conclusions.

There is also some difference of opinion as to the per cent of chemical which should be present in a carburizing mixture. In 1861 Caron proposed a mixture consisting of 60 per cent wood charcoal and 40 per cent barium carbonate. This mixture is still

given in some of the modern books on heat treating, and yet out of more than 20 commercially manufactured carburizing compounds the writer has had occasion to test not one contains as much as 40 per cent of barium carbonate or any other chemical. Furthermore tests have indicated that there would be no advantage in using as much as 40 per cent of any chemical energizer.

Several years ago the writer ran a series of tests on a number of different mixtures of charcoal, coke and chemical. Much to his surprise it was found that the depth of case and the per cent of carbon in the outer layer of the case did not increase every time that the per cent of charcoal and chemical in the carburizing mixture was increased. After the per cent of chemical had been raised to a certain figure, further additions of chemical seemed to make no difference whatever in the carburizing action. On the other hand when the per cent of chemical was below that figure it was found that both the speed of penetration of the carbon and the per cent of carbon in the outer layer was decidedly less. It seemed therefore that there was a certain amount of chemical which would give the fastest penetration and the highest per cent of carbon. A higher per cent of chemical produced exactly the same results, but a lower per cent of chemical produced inferior results. In other words there seemed to be a breaking point in chemical composition below which the per cent of chemical should not be allowed to fall. This conclusion has been verified a number of times since.

This may at first seem peculiar in light of Giolitti's statement that the carburizing action increases as the quantity of gas which comes into contact with the steel is increased. It would seem that the more chemical there was present the greater would be the quantity of gas evolved. It is entirely possible that the chemical decomposes and gives off gas until a certain pressure is reached in the box, and that when this pressure is reached a further evolution of gas is prevented. This would follow the general rule of the generation of gases from solid and liquid materials by heating. For example, if water is heated in a closed container it will boil and give off steam until the steam pressure becomes high enough to prevent further boiling.

If it may be assumed that the above explanation is correct it follows that not all of the chemical present in the carburizing

box is decomposed. Probably only a certain amount of gas can be given off under any given condition of temperature and pressure. Of course when gas leaks out of the box and the pressure in the box is reduced, more gas could be given off until the pressure is again built up to the point where it stops the evolution of the gas. If these assumptions are correct it can easily be understood why only a certain amount of chemical is necessary to produce the maximum carburizing under a given set of conditions of temperature and pressure.

The exact per cent of chemical which constitutes the minimum necessary to produce the maximum amount of carburizing probably depends upon the chemical that is used. Some carbonates yield more gas in proportion to their weight than others. No matter what chemical is selected it is well to use more than the bare minimum which will give good results. Some allowance must be made for loss in handling. It would be safe to recommend that the chemical content in a new material should be at least twice the theoretical minimum which will produce good results.

Composition of Commercial Compounds. There are so many different carburizing compounds on the market that it is hard to give typical compositions. Some are entirely coke-base, that is they are mixtures of coke and chemical, others are charcoal-base, (mixtures of charcoal and chemicals), while another class contains both charcoal and coke as base materials. The proportions of charcoal and coke in the last mentioned class varies with the different compounds. Some specifications call for a maximum of 25 per cent coke while others permit as much as 50 per cent coke.

The chemical content also varies in the different compounds. One class contains about 8 to 12 per cent of sodium carbonate as the only chemical energizer. Others contain little or no sodium carbonate but contain one or both of the other energizers. Quite a number of compounds contain all three of the common energizers. The total chemical content seldom exceeds 25 per cent.

Other Chemical Energizers. The three chemical energizers mentioned are the most common but others are possible. Common salt (sodium chloride) is sometimes used. While this salt does not yield any carbonaceous gas it is said to speed up the carburizing action. On the other hand it may cause pitting of the steel particularly if there is any considerable amount of moisture present in

the compound when packed. Cyanides are objectionable because they produce sudden cases and because they are poisonous.

Manufacturing the Compound. If it is desired to produce uniform results it is necessary that the carburizing compound itself be uniformly mixed. In fact it is more important that the composition of the compound be uniform than that it shall contain a certain amount of chemical.

Several years ago the writer conducted a series of tests to determine the effect of uniform or non-uniform mixing of the chemical with the other ingredients. It was found that when all the chemical was at the bottom of the pot, very non-uniform carburizing was produced. The steel just above the chemical received the most case while the steel at the top of the pot received much less. A uniformly mixed compound gave uniform results from top to bottom. Pure wood charcoal without chemical produced inferior results.

Granting then that uniform mixing of the constituents is of the utmost importance in the manufacture of a carburizing compound, the question arises as to how this is to be accomplished. First the chemical and the charcoal and coke or other constituents must be uniformly mixed. A mixer of the type used in mixing concrete will accomplish this, but if the chemical is left loose in the mixture it will tend to settle to the bottom when bags or barrels of the material are shipped or handled. There may be the same tendency when the material is placed in the carburizing boxes, particularly if the boxes are shaken when packed. This would produce a non-uniform condition in the carburizing boxes similar to that mentioned in the test just described.

It is important not only that the chemical be *mixed* uniformly with the charcoal and coke or other materials but that it be *permanently bound* to the other ingredients. In fact it should be so well bound that it will not separate on handling or use.

This may be accomplished in several ways. One method consists in grinding all of the constituents to dust and after mixing them with some binder to roll them into pills or pellets. Sometimes these pellets are heated and coked. In another method the base material consists of small granules of charcoal or coke or both. The chemical mixed with a binder is coated on the surface of the particles of the base material. Sometimes the compounds are

dried or heated after coating and sometimes they are not. As a variation of these methods fine carbonaceous material may be mixed with the chemical and the binder and the mixture is coated on the base material. Still another method consists in "impregnating" the chemical in the pores of the base material. This requires the use of a soluble energizer. A solution will pass through the pores of charcoal but insoluble matter will not.

The foregoing description is given without any prejudice with regard to the different methods. As a matter of fact good compounds have been manufactured by all of the methods. It is also true that poor compounds may be manufactured by any of the methods if the process is not properly carried out.

The writer has also avoided any expression of opinion as to whether the user should buy a commercially manufactured compound or make his own. Either may be done successfuly if the material is manufactured properly. On the other hand too much stress cannot be placed upon the fact that the manufacture of a good carburizing compound is not as simple as some think and that no matter who does the work the compound must be properly made or uniform carburizing will not be produced.

The above discussion has been limited to compounds containing charcoal, coke, and carbonates. It should be mentioned that some believe that the addition of a considerable amount of oil improves a carburizing compound. When such a compound is heated the oil is vaporized long before the carburizing temperature is reached. If there are any oil (hydrocarbon) vapors left in the carburizing box when the carburizing temperature is reached, there is no doubt that these vapors will add carbon to the steel. The opponents of the oil-soaked materials claim that the oil vapors will be entirely gone before the carburizing temperature is reached. This will depend largely upon how well the box is sealed. It seems probable that in a well-sealed box there will be a considerable amount of oil vapors remaining in the box at the carburizing temperature. It seems equally probable, however, that a great deal of the oil will be used up during the first heat.

REUSE OF CARBURIZING COMPOUNDS

The ideal carburizing compound should be capable of being used over and over with the addition of the minimum amount of new material. This addition of new material is necessary in order

to make up for losses which occur in the use and handling of the material.

It has already been explained that the chemical (carbonates) decompose on heat but are regenerated on standing in contact with air, so that theoretically there should be no loss of the chemical on use. On the other hand when the compound is handled or when the base materials burn slightly during the carburizing heat, the chemicals may come loose from the base materials to some extent. The loose chemicals may be lost in subsequent handling, screening or fanning, or if left in the compound they may settle to the bottom of the box when the compound is packed the second time.

When a compound containing charcoal and coke is heated to the carburizing temperature the charcoal is burned faster than the coke. As a result there is a tendency for the coke content to increase with repeated use. When a compound loses charcoal and chemical it loses some of its strength as a carburizing material. This loss of strength should be made up by the addition of charcoal and chemical or by the addition of enough new compound (containing the usual amount of charcoal, coke and chemical to assure that the content of charcoal and chemical is above the necessary minimum. A charcoal-base compound (one containing charcoal and chemical only) or a coke-base compound (one containing coke and chemical only) is somewhat simpler as there is not the constant change in the proportion of the base materials present.

Obviously there must be enough new material added after each heat to make up for the loss of volume due to losses in burning and handling. From this standpoint a compound having a low shrinkage and yielding little dust should prove economical. There is some difference of opinion as to whether a carburizing material should be screened after use. Screening may result in the loss of some of the chemical energizer. On the other hand if the material is not screened there will be a gradual accumulation of dust or ash which does no good in carburizing and may do harm. In general, a carburizing material tends to become finer and more dusty the longer it is used without screening. The finer and more dusty it becomes the more it will weigh per cubic foot, the tighter it will pack in the boxes and the slower the heat will penetrate into the center of the carburizing box.

Summing up it may be said that enough new material has to

be added to make up for shrinkage and loss in handling. If that is not enough to keep the material up to strength, enough more new material must be added to accomplish this. For every kind of material there is an amount of new which is necessary in order to keep the compound up to strength. Contrary to the popular belief in some places adding more than this amount does not speed up the carburizing action. In many places the carburizing compounds are used wastefully. After adding the necessary amount of new it is imperative that the new and old be thoroughly mixed.

Carburizing Containers

Next to the selection of the steel and the carburizing compound comes the selection of the pots or boxes used for carburizing containers. One of the first requirements of a good carburizing container is that it must be capable of being sealed tightly. Poorly sealed boxes mean excessive burning of the carburizing material, loss of carburizing gases, and low pressure in the box. A few years ago is was not uncommon to see carburizing boxes used without covers. Sometimes the box was "sealed" by a layer of clay over the top of the carburizing compound. Usually this clay seal cracked and did not do much good.

One of the worst conditions exists when a pipe is packed with steel and compound, and after the ends sealed with clay is placed in a horizontal position in the furnace. If the seal at each end cracks there may even be a circulation of air or furnace gases through the top of the pipe after the compound has burned down. One of the worst cases of decarburizing after carburizing the writer has seen was the result of this method of packing. A long shaft placed in the center of the pipe might be carburized all right, because the burning down of the compound would not cause the shaft to become uncovered. On the other hand if a number of shafts were placed in the pipe close to the walls instead of in the center, it would be almost certain that one of them would become uncovered toward the end of the heat, if the pipe was laid horizontally in the furnace. This would mean decarburizing. Recently there have been developed some special carburizing tubes with tight sealing covers which prevent the leakage of gas and air and the decarburizing action.

When pots or boxes are used they should be provided with tight fitting lids. In this connection it may be added that it is

difficult to keep a lid tight fitting on a cast iron or plain steel pot. There are, however, alloy pots and boxes on the market which do not warp or change shape to any great degree during use. It is possible to keep the covers tight fitting on such pots and boxes.

The inverted type is even more desirable. After the box is packed and covered the box is placed in the furnace so that the pot rests on the lid. Thus the seal is made by the weight of the box instead of the weight of the cover. For the same reason the pressure of gases obtainable in the box is greater when the inverted type box is used. Another advantage of this type is that the joint between the cover and the box appears at the bottom instead of the top when the box is in the furnace. When the ordinary "right end up" box is used, the burning down of the carburizing material during the carburizing run leaves a vacant space just below the lid. There may be a tendency for the gases to leak out or for air or furnace gases to be sucked into the box between the box and the lid. If the top layer of steel is too near the top of the box it way become uncovered by the burning of the carburizing compound and consequently become exposed to the furnace gases. This will cause decarburizing. Even when the steel is not actually uncovered it is sometimes decarburized by the gases in the top of the box.

When the inverted type of box is used this cannot happen. It is true that the compound again burns down in such a box, but the joint between the box and the cover appears at the bottom. Any air sucked in through this joint immediately comes into contact with the carburizing compound and is converted into carbon monoxide which is a carburizing gas.

It is well to have the shape of the container conform to the shape of the work to be carburized if practicable. For example large gears are packed in round boxes while shafts may be packed in rectangular ones. The large differential ring gear is frequently packed in the "chimney type" box. This is a round box having a vertical hole or chimney through the center. When a large number of different parts of varying sizes and shapes must be handled it is not practicable to have a box designed for each different part. It becomes necessary to standardize on a few different sized boxes.

The life of a carburizing box depends upon the metal of which

the box is composed and the conditions to which the box is exposed.
There are numerous heat resisting alloys on the market which are
recommended for carburizing boxes. These range in composition
from alloys which are largely nickel and chromium with only a
little iron down to steels which are largely iron containing compar-
atively small amounts of nickel or chromium or both. Some other
alloying elements may also be added in addition to nickel and
chromium. Up until comparatively recently practically all boxes
were cast. Lately there has been considerable work done along the
line of development of a sheet metal box. In the present discussion
any statement of preference for any type or composition is obvi-
ously out of place.

PRACTICAL OPERATION OF CARBURIZING

Packing for Carburizing. The rules for packing for carburiz-
ing are extremely simple. The work to be carburized should be
packed in such a manner that all surfaces which are to be carbur-
ized come into contact with a layer of carburizing compound.
These surfaces must not touch each other or the sides or bottom of
the container. Surfaces which need not be carburized may touch
each other. Thus gears are sometimes packed hub to hub but there
is an ample layer of compound around the teeth. When the "right
end up" box is used there must be enough compound above the
top layer of work to assure not only that the work will not be
uncovered but that there will still be at least an inch of compound
above the work at the end of the heat. It is usually well to shake
down the box after packing and fill it level full with compound
after shaking.

Lids may be luted on the right end up boxes with fireclay
if necessary although self sealing lids are much preferred. It is
frequently found that used compound contains a considerable
proportion of fine fireclay. The inverted boxes should need no
clay for sealing.

PROTECTION AGAINST CARBURIZING

It is often desired to carburize some parts of a piece without
carburizing others. One of the best preventions against carburiz-
ing is good copper plate. Sometimes the entire piece is copper-
plated and then the plate removed from the portions to be carbur-
ized. Another method consists in coating the portions which are

not to be plated with paraffine or some similar material before immersing in the plating bath. The copper plate must be good or it will not prevent carburizing. This means that the steel should have a well-machined clean surface before the plate is applied and that the plating must be done in a manner to produce an A1 plate. Another method of protecting localities against carburizing consists in covering them with fireclay or some mixture which is impervious to the carburizing gases. Among the materials used in making protective coatings may be mentioned, kaolin, water glass (sodium silicate), silocel, zircon, and asbestos. There are a number of commercially prepared anti-carburizing paints on the market. One of the principal difficulties is to manufacture a material which will stay on and prevent carburizing and yet come off readily after the case hardening operations are completed. Clay alone is inclined to crack when heated and let the carburizing gases through. Some of the materials containing water glass stick very well during heating and afterwards also. They may crack off the exterior surfaces when quenched in water but adhere very well in screw threads and holes. Threaded ends are sometimes protected by screwing a metal cap or plug on or in the threads, before carburizing.

Still another method of producing selective case hardening does not involve protecting against carburizing. Only the portions to be hardened are finished machined before carburizing. The piece is then carburized all over and then finish machined. This removes the case from all of the portions except those which it is desired to harden. Of course differential hardening may be produced by carburizing all over and only hardening one portion or hardening all over and tempering one part more than another.

CARBURIZING FURNACES

The first requirements of any carburizing furnace are that it shall heat each box uniformly to the desired carburizing temperature and that it shall maintain the contents of each box at the carburizing temperature for the same number of hours. The carburizing furnaces may be divided into two general classes, the batch type and the continuous type.

Batch-Type Furnaces. The ordinary batch-type furnace is a simple oven or "box type" furnace into which a number of carburizing boxes are placed. The oven may be heated with coal, oil, gas or electricity. As a general rule all of the boxes are charged

into the furnace at the same time and they are removed the same way. In order to do uniform carburizing it is obviously necessary that all of the boxes shall be heated at the same rate of speed. If one box reaches the carburizing temperature before the others do, it means that that box will be maintained at the carburizing temperature longer than the others. This means a lack of uniformity in the depth of case on the work in the different boxes.

Coal, oil, gas and electricity have all been used in heating carburizing furnaces. The writer obviously wishes to avoid entering into the discussion of the relative merits of the different furnaces. On the other hand the once prevalent idea that any kind of a furnace is good enough for carburizing cannot be too strongly condemned. There is probably no other operation in the heat treating department which demands a greater uniformity of heating of all parts of the furnace.

Electricity is the most expensive source of heat, but it is a simple matter to obtain a constant and a uniform temperature in all parts of a well designed electric furnace. On the other hand the more modern types of gas furnaces also distribute the heat very uniformly. Oil is a more difficult fuel to handle than gas, due to the possibility of clogging of burners and valves and uneven flow of oil to the different burners, but the writer would not wish to say that oil furnaces cannot be built which would heat uniformly. The coal-fired furnace is the most difficult of all to control. No one knows what future developments may bring in the control of the different types of furnaces.

No matter what fuel is used the operation should be as simple and as automatic as possible. Gas, oil, and electric furnaces are now successfully controlled by automatic pyrometer controllers so that the temperature of the furnaces is held quite constant.

Continuous Furnaces. Very recently continuous carburizing furnaces have come on the market. These may be divided into three general types: the rotary, the straight through, and the counter flow. In the rotary furnaces the boxes are placed on a rotating circular hearth. As the hearth turns the boxes are gradually brought to the carburizing temperature and are kept at that temperature until they reach the discharge door, where they are removed from the furnace. In the straight through furnace the boxes are slowly pushed through a long rectangular oven and are

discharged while at the carburizing temperature. Either of these types is suitable for direct pot quenching.

The counterflow furnace is a variation of the straight through furnace. Two or more rows of boxes are pushed in opposite directions through the furnace. The furnace is divided into three zones; a hot zone in the center and a heat interchange zone at each end of the furnace. The hot boxes coming out of the center zone give up some of their heat to the incoming boxes in the end or heat interchange zones. When removed from the furnace the boxes are well below the carburizing temperature. As a variation of this method the furnace may have a hot zone at one end and an interchange zone at the other. The box enters the heat interchange zone, passes through to the far end of the hot zone and returns through the hot zone and the interchange zones and is discharged at the same end that it entered. These furnaces are only applicable to work which is to be cooled slowly from the carburizing temperature.

These continuous furnaces are very economical to operate if they are kept full 24 hours a day 7 days a week. Obviously they are not so desirable unless there is sufficient production to keep them going steadily.

GAS CARBURIZING

Considering the fact that it is really gas that carburizes steel, no matter whether the carburizing material is originally a solid, a liquid or a gas, it would seem natural to carburize directly with a gas. This was done on a laboratory basis by Giolitti and other experimenters. Numerous tests have been made using different carbonaceous gases and varying the conditions of temperature, pressure and rate of flow of the carbonaceous gas. The results produced have varied all the way from no carburizing to very good carburizing. No attempt will be made to even summarize these results here.

Gas carburizing is being successfully performed on a commercial basis in quite a number of industrial plants in this country. The furnaces most commonly used may be divided into two general types:—the revolving retort, and the stationary retort furnaces. The former is a horizontal barrel-type furnace having a cylindrical retort or drum in the center. The retort is heated by flames passing

around it. The front end of the retort is closed by a cover of the same diameter as the retort, while the rear end is solid. The work is placed inside the retort and the front is closed. Gas is admitted through a pipe in the center of the rear end of the retort. The cover at the front end is provided with a pipe and a valve which is cracked open so as to allow the gas to pass slowly out of the retort. Thus a circulation of gas through the retort is established. The retort is continually revolved at a slow speed causing the work to tumble over and be uniformly exposed to the gas. After the work has been thus exposed to the gas at the carburizing temperature for enough hours to produce the required depth of case, the cover is removed and the whole furnace is tilted forward discharging the work, either into the quenching tank or into suitable metal containers.

It is obvious that this method is not applicable to gears, long shafts and other parts which will not stand a moderate amount of tumbling at the carburizing temperature. For such parts a vertical stationary retort is employed. The retort is loaded from the top, the work being placed so that the gas can reach all surfaces to be carburized. This may require the use of suitable racks for holding the work.

There are numerous advantages of these methods of gas carburizing. As neither carburizing boxes nor carburizing compounds are employed, the result is the elimination of the cost of purchase and maintenance of boxes, and compounds, labor of packing boxes, mixing and handling compound, and the costs of heating of boxes and compound. Furthermore the floor space required is much less.

On the other hand gas carburizing is far from fool proof. In some places the method has been carried out day after day with excellent success while in others irregular and sometimes inferior carburizing has been reported. Like all other carburizing furnaces these gas carburizers must heat absolutely uniformly in all parts or uniform carburizing will not be produced. This is a problem for the men who install and operate the furnaces. The nature of the gas used, the rate of flow, the time, the temperature and the pressure are all important factors which govern the results. Some have reported that natural gas is a better carburizer than artificial gas. Even variations in the behavior of city gas has been reported. This latter point and the methods of correction

has been discussed by Guthrie. Some work has also been done with the use of vaporized oil in place of gas.

It should also be mentioned that solid carburizers are sometimes used in the rotary retort in the place of gas. The usual amount of work is charged into the retort along with a few shovel fulls of compound. This method is sometimes successful when gas carburizing is not and the economies are about the same.

CONTROL OF DEPTH OF CASE

No matter what method of carburizing is employed the control of the depth of case is very important. For every article that is case hardened there is a proper depth of case. Sometimes it is necessary to hold the depth of case within very close limits. If the case is too deep there may not be enough core left to give the article the required toughness. On the other hand if parts such as gears and bearing races which must withstand localized pressures, have cases that are too thin there will be danger of the case being dented in causing cracking or spalling of the case.

There is some difference of opinion as to how the depth of case should be measured. A carburized, slowly cooled specimen when examined under the microscope exhibits a case consisting of three zones: a high carbon or hypereutectoid zone at the surface, an eutectoid or 0.85 per cent carbon zone in the center of the case, and a hypoeutectoid or graduation zone in which the carbon content gradually decreases from 0.85 per cent to the normal carbon content of the core. It is sometimes difficult to draw a sharp line between the end of the case and the beginning of the core.

For measuring the depth of case under the microscope it is most convenient to use a micrometer eyepiece having a scale which when used with the proper objective will read directly in thousandths of an inch. The measuring of cases under the metallurgical microscope is necessarily slow, as the specimen must be allowed to cool slowly after carburizing, after which a cross section must be cut, polished and etched. The method has some advantages as the per cent of carbon in the various layers of the case may be estimated at the same time that the depth of case is measured. Decarburizing is also easily seen under the microscope. This is a laboratory method rather than a rapid production method. When using the microscope it is much better to examine a specimen which

has cooled slowly from carburizing than one which has been hardened.

The more common production methods of determining the depth of case depend upon the examination of the fracture of a hardened specimen. The apparent depth of case as shown by the fracture will vary somewhat depending upon the hardening temperature. Sometimes it is difficult to see the dividing line between the case and the core. The case can be brought out more clearly by etching in dilute nitric acid or by heat tinting. In the latter method, the specimen is heated to about 600 degrees Fahr. when the case turns blue while the core remains straw or brown. The fracture must be exposed to air while heating as the color is due to oxidation. The actual measuring may be done with an ordinary steel scale and a magnifying glass or with a Brinell microscope.

Unfortunately the different methods of measuring the case do not give exactly the same results. This sometimes causes misunderstandings. It is best for the manufacturer to standardize on one method of measuring case and to specify case depth on that basis.

The most convenient specimens for measuring case depth consist of small pins of the same kind of steel as the production work. These should be placed well beneath the surface in the carburizing box. A small pin will get approximately the same depth of case as the work in the same box although the work may be considerably larger. This is due to the fact that the carburizing boxes heat through so slowly that small and large pieces are heated at about the same speed. On the other hand boxes containing different weights of steel will not heat at the same rate of speed. It is well to keep the total weight of steel in each box in the same heat as nearly uniform as possible.

When the carburizing is done in box-type furnaces it is possible to remove one box from the furnace at the end of the run, and remove, quench, break and examine the test pin before the entire charge is removed from the furnace. If the depth of case is insufficient, the boxes can be left in the furnace longer. Pins placed in different positions in the boxes and in different boxes in the furnace give the best indication of the uniformity or lack of uniformity of heating of the furnace. These test pins frequently

give indication of irregularities before they are caught in any other way. Test pins are also useful when continuous furnaces are used, although it is obviously impossible to hold the charge in the furnace while waiting for the test. On the other hand, once a continuous furnace is properly adjusted, irregularities are much less likely to develop. When gas carburizing retorts are used it is best to place test pins in different position in the retort as a check on the uniformity of the carburizing produced.

If the furnace is designed and operated correctly and if all of the conditions are the same for every run, it should be possible to produce the required depth of case by leaving the boxes in the furnace a certain number of hours and maintaining the furnace at a given temperature. With the most modern furnaces, particularly the continuous furnaces, this can be done to a remarkable degree of accuracy. When batch-type furnaces are used there are a number of variable conditions which affect the rate of heating and consequently the depth of case that will be obtained in a given number of hours. Among the variables may be mentioned: the temperature of the furnace at the time of charging, the ratio of the size of the furnace to the weight of the charge, and the rate of input of heat into the furnace during the heating period. The weight of the charge includes the number of boxes and the weight of the steel and compound packed in the boxes. The weight of the boxes as packed may vary considerably depending upon the shape of the pieces carburized. It is advisable to work out a packing schedule so that all boxes will contain approximately the same weight of steel. It is sometimes found that furnaces heat slower the first day after a week end shut down even though the temperature as indicated by the thermocouple at the time of charging is the same that day as other days in the week. This is due to the fact that the lining is not always thoroughly heated through the first day. Consequently there is more heat going into the lining during the first day than on succeeding days.

No matter how good the furnace the use of test pins as a check on the carburizing is not amiss. It is universally accepted that in a machine shop an inspection is advisable no matter how perfect the automatic machinery may be. The same principles apply in the heat treating department.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,668,355, **Pickling Apparatus, William J. Cook, of Wheeling, West Virginia.**

This patent describes a pickling apparatus for pickling sheets or the like comprising a pair of pickling baths 3 over which is suspended a rocking crane 1 supported in trunnions 2 provided with arms 4 and 4a for receiving the beams 10 in the trunnion seats 9 which support the racks 12 on which the plates are mounted. In the operation of the device, the arms
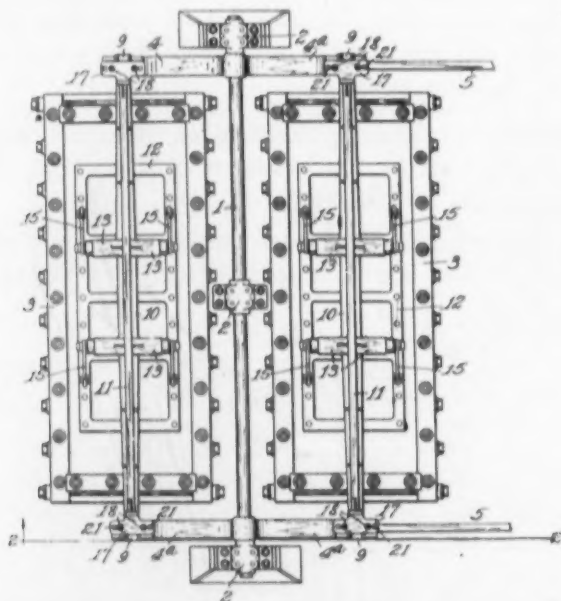
4 are rocked about the trunnions 2 to alternately raise and lower the racks 12 into and out of the pickling solution and the beams 10 supported on the trunnion seats 9 also cause the racks to travel in the arc of a circle giving a slight lateral movement in addition to the vertical movement which tend to spread the sheets in the bath allowing prompt access of the pickling solution to all the surfaces thereof. The beams 10 are removable from the trunnion seats 9 for the purpose of loading and unloading the racks.

1,668,642, **Manufacture of Alloys, William M. Grosvenor and Victor P. Gershon, of New York, N. Y.; said Gershon Assignor to said Grosvenor.**

This patent describes an apparatus for the manufacture of alloys of nickel and zinc adapted to be later alloyed with fine gold to produce a workable white gold. The apparatus comprises a cast iron container 4 pro-

vided with a heat insulating lining 8 inside of which is the vessel 9 of carborundum, containing a plurality of dishes 10, 11 and 12 of refractory material and a layer of carbon resistor grains 13 around the bottom and sides of the dishes 10, 11 and 12. Electrodes 18 and 19 extend through the walls of the container 4 and into the resistor grains 13 to make electrical connection therewith and a cover is provided for the container 4 adapted to
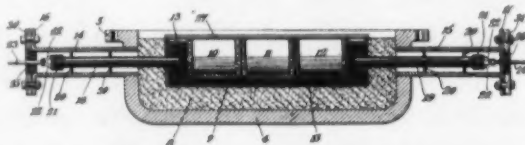
be securely bolted to the flanges 5 in an air tight manner, so that after placing the nickel and zinc in the dishes 11 to be melted the air may be exhausted from the container and inert gas, preferably nitrogen, pumped into the container to a sufficient pressure to prevent material loss of the zinc by volatilization. The base alloy of nickel and zinc thus formed may be readily alloyed with fine gold to produce white gold which may be readily cast and rolled for making jewelry.

1,670,495, Method of Cutting Slots with Rotating Tip, Clarence J. Coberly, of Los Angeles, California, Assignor to Kobe, Inc., of Los Angeles, California, a corporation of California.

This patent provides a cutting torch having a combustible gas passage 19 feeding the tips 20 and a cutting gas passage 59 adapted to be rotated
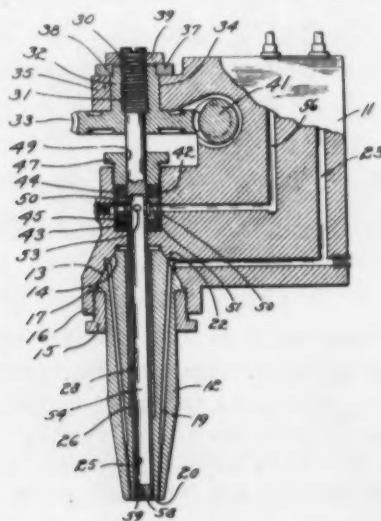
by means of the worm 33 and worm wheel 41 so as to cut a hole or slot having non-parallel side walls by the revolving of the cutting gas around the axis of the tip. The inlet for the cutting gas is indicated at 56 and for the preheating, or combustible, gas is indicated at 23 suitable means of communication being provided by means of the slots 22 and the holes 53 between the inlet passages and the rotating tip.

1,670,846, Zoned Resistor for Electric Furnaces, Frank T. Cope, of Salem, Ohio, Assignor to The Electric Furnace Company, of Salem, Ohio, a corporation of Ohio.

This patent describes a zoned electric furnace intended to regulate the degree and amount of heat applied at various portions throughout the length of a continuous furnace and to control the application of current to the various zones. The furnace 1 is divided into zones 2, 3, 4 or more, the first zone having resistors connected by the wires 5 to receive 60 kilowatts of electrical energy. The resistors in zone 3 are connected by the wires 6 to a source adapted to deliver 30 kilowatts and the resistors
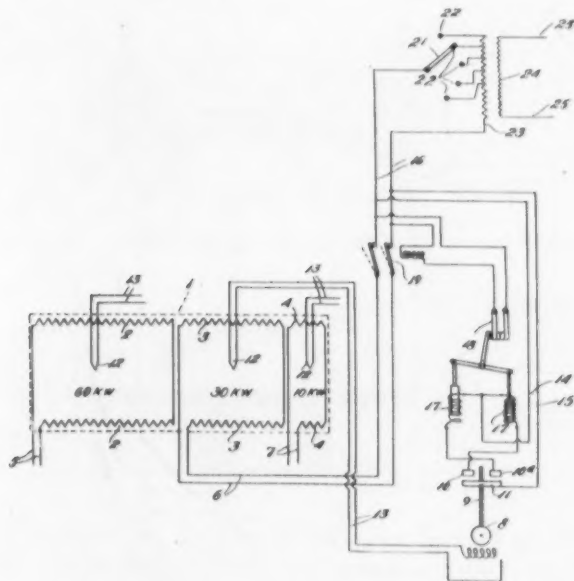
in zone 4 at the discharge end of the furnace may receive 10 kilowatts through the wires 7. By this arrangement the material entering the zone 2 is adapted to be brought up to the desired temperature in a comparatively short time due to the larger amount of energy liberated in this zone and to be retained at the desired temperature in passing through the zone 3, whereas if the furnace were uniformly heated throughout, the time of heating would be longer. Thermocouples 12 in each zone connected to contact pyrometers provide automatic means for controlling the application of power to the various zones.

1,671,034, Case Hardening, Andreas Lennartz, of Near Aachen, Germany.

This patent describes a protective material to prevent carburization of selected portions of metal undergoing case hardening. The improvement consists in adding ferrous sulphide to the kaolin or loam protective masses now used, the ferrous sulphide preventing the penetration of carbon into the portions of the article protected thereby.

1,671,337, Soaking Pit, Thaddeus F. Baily, of Alliance, Ohio.

This patent describes a soaking pit or furnace adapted to receive ingots or other articles and to have the heating elements located above the articles so that the heat is radiated downward toward the bottom of the pit. The pit comprises any number of suitable compartments 1 provided with a firebrick side and bottom walls over which a removable cover 5 is adapted to be placed and to rest in a sand trough 3 around the upper part of the pit 1. The interior of the pit is adapted to receive ingots or the like 17 in upright position and the removal cover 5 is provided with
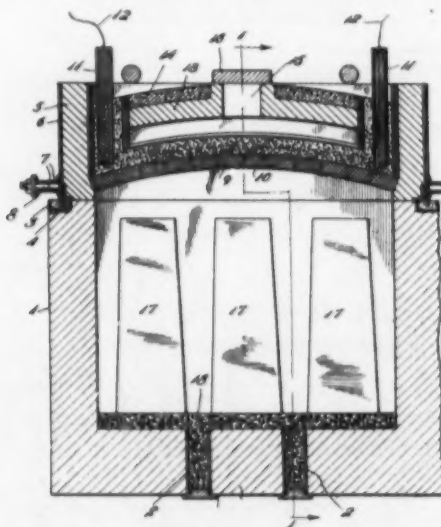
electric resistors 9 formed of silicon carbide or the like and adapted to contain a granular resistance material 10 into which electrodes 11 project. The invention also provides a ready means for converting any existing type of gas heated soaking pit into an electrically heated pit by providing the electrically heated cover 5.

1,669,649, Magnetic Material, Charles Philip Beath, of Chicago, and Herbert Martin Edward Heinicke, of Elgin, Illinois, Assignors to Western Electric Company, Incorporated, of New York, N. Y., a corporation of New York.

This patent describes a process of producing powdered brittle magnetic alloys for use in electrical signalling apparatus, such as cores for loading coils employed in telephone circuits. The process comprises heating iron and nickel in the presence of an oxidizer, such as iron oxide, to bring about oxidization of the iron and nickel and fusion of the same and then passing hot billets from the heating furnace through reducing rolls to form flat strips of about one-quarter of an inch in thickness which are subsequently cut into short pieces and crushed in a jaw crusher, the fine grain structure brought about by the reducing rolls facilitating the breaking of the alloy into fine dust. A preferred composition consists of 78½ parts of nickel and 21½ parts of iron.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

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AIRCRAFT

MANUFACTURE—METALLURGY. Aircraft Metallurgy, H. C. Knerr. *Am. Soc. Steel Treating—Trans.*, vol 13, no. 5, May 1928, pp. 723-753 and (discussion) 753-758, 14 figs.

Outlines metallurgy of aircraft manufacture, touching upon such features as choice of materials, specifications for purchase and inspection thereof, properties of principal metals used, processes of machining, forming, riveting, welding, brazing, foundry practice, and corrosion prevention, and discussing methods of metallurgical control; causes of failure and their prevention. Bibliography.

ALLOY STEELS, AIRCRAFT

Light Alloys for Aircraft Work. *Aeroplane (Lond.)*, vol 34, no. 16, Apr. 18, 1928, p. 568.

Method of High Duty Alloys Ltd. in making light alloys in quantities with laboratory-like accuracy; scrupulous cleanliness of plant; exceedingly careful control over composition of all alloys made; precise quantity of each element put into furnace is directly controlled by metallurgist; products found to be exceedingly uniform; high tensile strength of Hiduminium.

ALLOY STEEL CASTINGS

General Characteristics of Alloy Steel Castings, J. W. Frank. *Am. Foundrymen's Assn. —Reprint*, no. 28-8, for mtg. May 14, 1928, pp. 119-128.

Deals with manganese, nickel-chromium, high nickel-chromium heat-resisting, chromium, molybdenum and chromium-vanadium steels; care in manufacture of alloy steels.

ALLOYS, HEAT RESISTING

Heat-Resisting Alloys (Hitzebesteandige Legierungen), W. Rohn. *Korrosion and Metallschutz (Berlin)*, vol. 4, no 2, Feb. 1928, pp. 25-28, 7 figs.

Chemical changes produced in metals and alloys by high temperatures of about 1000 degrees Cent.; illustrations from furnace and ceramic oven practice, economy of special alloys. Paper read at Berlin Werkstofftagung of 1928.

ALUMINUM—CORROSION

Investigation of Corrosion of Aluminum (Bericht ueber Untersuchungen zur Korrosionsfrage des Aluminiums), W. Guertler, *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 3, Mar. 1928, pp. 104-112, 19 figs.

Results of earlier research; theory of aluminum corrosion; injurious and harmless chemicals; recommendations based on results of author's investigation.

ALUMINUM—UTILIZATION

Use of Aluminum and Aluminum Alloys in the Chemical and Food-Products Industries (Die Bedeutung des Aluminiums und seiner Legierungen fuer die chemische Industrie and die Nahrungsmittel-Gewerbe), H. Buschlinger. *Chemische Fabrik (Berlin)*, no 16, Apr. 18, 1928, pp. 209-211.

Discusses resistance of aluminum to corrosion, strength of plates of aluminum and aluminum alloys at various temperatures, special instructions for manufacture of aluminum containers.

ALUMINUM ALLOYS, AIRCRAFT

Lautal (Lautal als Baustoff fuer Flugzeuge), P. Brenner. *Zeit. fuer Flugtechnik u.*

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

Motorluftschiffahrt (Munich), vol 19, no. 3,
Feb. 14, 1928, p. 63.

Product of Vereinigte Aluminum Werke, A.
G., Lautawerk, Germany; differs chemically
from duralumin mainly in that it contains no
magnesium; this difference causes aging to
take place only at temperatures above atmos-
pheric; it is said that this makes working of
Lautal more convenient than that of duralu-
min.

Light Metal Alloys in Aircraft Construction
(Die Leichtmetalle im Flugzeugbau), P.
Brenner. Zeit. fuer Flugtechnik u. Motorluft-
schiffahrt (Munich), vol. 19, no. 6, Mar. 28,
1928, pp. 121-124, 7 figs.

Properties of duralumin and other alloys
of aluminum, magnesium, etc., used in con-
struction of aircraft; corrosion of metal parts
of aircraft and its prevention.

ALUMINUM ALLOY CASTINGS

Evolution of Aluminum-Alloy Casting Sys-
tems (La evolucion de los sistemas de fundir
en las aleaciones de alumino), A. Llorens and
Mayiques. Anales de la Asociacion de In-
genieros (Madrid), vol. 7, no. 38, Mar., 1928,
pp. 121-129, 7 figs.

Comparison of ordinary chill-mold and die
casting; casting in sand molds is limited to
small output of large-size parts; quantity
production of uniform quality more con-
venient in metal mold; simple parts in ordina-
ry shell mold; large output of small parts,
or complicated parts even if few in number,
best produced by pressure die-casting system.

Effect of Melting and Pouring Conditions
Upon the Quality of No. 12 Aluminum Alloy
Sand Castings, T. W. Bossert. Am. Foundry-
men's Assn.—Reprint No. 28-27, for mtg.
May 14, 1928, pp. 427-438, 5 figs.

There appears to be definite relationship
between crystal size and drawing, in that
coarsening of crystal structure indicates in-
creasing tendency for draws to appear, with
constant pouring temperature, increase of
melting temperature produces increase of
crystal size and causes drawing; conclusions
emphasize necessity for accurate control in
No. 12 alloy melting.

ALUMINUM ALLOYS—CORROSION

Effect of Some Electrolytes on Aluminum
and Aluminum Alloys, N. A. Isgarishev and
V. M. Jordansky. Jl. Russkovo Physico-Chi-
micheskovo Obshchestva (Leningrad), vol. 60,
no. 1, 1928, pp. 113-126, 8 figs.

Experimental study of corrosive or dissolv-
ing effect of HCL and KOH on some alumi-
num alloys; found resistance to corrosion in-
versely proportional to copper content of al-
loys. (In Russian.)

ALUMINUM ALLOYS—
ELECTROPLATING

Electroplating on Aluminum and Its Al-
loys, H. K. Work. Am Electrochem Soc.—
Advance Paper, no. 23, for mtg. Apr. 26,
1928, pp. 263-286, 11 figs.

Methods of plating common alloys; dip is
described for commercially pure aluminum,
which roughens aluminum and simultaneously
forms immersion layer on surface; where
strong alloys are plated, excellent product is
easily obtained, providing alloy has been sub-
jected to usual heat treatment; Mellon In-
stitute of Industrial Research experiments.

ALUMINUM BRONZE

Aluminum Bronze. Metal Industry (Lond.),
vol. 32, no. 16, Apr. 20, 1928, pp. 403-404.

Review of booklet issued by Aluminum
Bronze Mfrs' Inst., Washington, supplying in-
formation as to commercial aluminum bronzes
in such form that users of these alloys will
be able easily to select particular type of
material suited to his requirements.

Technical Information on Aluminum Bronze.
Am. Metal Market, vol. 25, no. 55, Mar. 22,
1928, pp. 6-9, 5 figs.

Supplies information about commercial alu-
minum bronzes in such form that user of
these alloys will be able to select particular
type of material suited to his requirements;
mechanical properties of aluminum bronzes;
effect of temperature on properties; corrosion
resistance; work and machining. Reprinted
from booklet issued by Aluminum Bronze
Mfrs'. Inst.

ALUMINUM CASTINGS—WELDING

Welding Aluminum Castings, W. Mason.
Metal Industry (N. Y.), vol. 26, no. 5, May
1928, p. 205.

Practical description of work involved;
aluminum or aluminum-alloy castings up to
¼ inch in thickness can be welded without
beveling joints; welders should avoid over-
heating castings during preheating.

ALUMINUM INDUSTRY—
DEVELOPMENTS

The Development of the Aluminum In-
dustry. Metal Industry (N. Y.), vol. 26, no.
5, May 1928, pp. 217-218, 1 fig.

Uses for permanent-mold castings; alumi-
num strong alloys can also be forged; great
interest shown in aluminum by manufacturers
who make or operate transportation; whether
it be railway cars, street cars, busses or auto-
mobiles. (Concluded.)

AUTOMOBILES—BODIES, STEEL

Sheet Steel for Automobile Bodies. Heat
Treating and Forging, vol. 14, no. 4, Apr.
1928, pp. 375-380 and 391, 10 figs.

Metallurgical study of low-carbon grade of
steel that is used for sheets; critical points
and transformations; banded structure; grain
growth; microstructural constituents; iron-
carbon diagram and its importance; thermal
critical points; cause of critical points; soli-
dification and cooling. (Continuation of
serial.)

CASE HARDENING

Facts and Principles Concerning Steel and
Heat Treatment. Am. Soc. Steel Treating—
Trans., vol. 13, no. 5, May 1928, pp. 848-
880, 16 figs.

Second series of articles on case-hardening,
explains mechanism of carburizing and ef-
fect of different heat treatments following it;
carburizing is due to solution of carbon into
steel from some carburizing gas; decarburiz-
ing may take place during carburizing; ef-
fect of five different heat treatments after
carburizing.

CARBONIZING. Carburizing Iron Or Steel
Parts Needing Wear-Resisting Surface, F. H.
Williams. Can. Machy. (Toronto), vol. 39, no.
9, May 3, 1928, pp. 37 and 40, 6 figs.

Most practical method; iron; steel; carbur-

izing operation; desirable depth; color test; photomicrographs; furnace.

CASTING, PERMANENT MOLD

Vacuum Principle is Applied to Permanent Mold Casting, E. Bremer. *Foundry*, vol 56, no. 7, Apr. 1, 1928, pp. 256-259, 6 figs.

Process developed from practices in molding and forming glass; operations consist essentially of opening vacuum line, dipping ingress of mold into molten metal, allowing proper time for solidification, opening mold and ejecting finished casting, cooling mild, smoking joints to make proper seal for vacuum, brushing out soot, and closing and clamping; control movement.

CASTINGS

CLEANING. Cleaning Room Progress Aids Production of Quality Castings, F. G. Steinebach. *Foundry*, vol 56, nos. 7 and 8, Apr. 1 and 15, 1928, pp. 264-267 and 274, and 308-313, 39 figs.

Apr. 1: Tumbling mills for cleaning castings; round and square types; control mechanism; removing dust; continuous tumblers; special water-tumbling barrels; hydraulic abrasive tumbler. Apr. 15: Grinding as economical method of removing excess metal from both ferrous and nonferrous castings; avoiding vibration; safety collars; wheel guards; portable equipment. (Continuation of serial.)

CHROMIUM ALLOYS

WELDING. Welding of High-Chromium Alloys. *Acetylene Jl.*, vol 29, no. 5, May 1928, pp. 449-451, 8 figs.

Survey of correct procedure for welding various types of these corrosion-resisting alloys; commercial chromium alloys are here divided into six groups in accordance with different prescribed methods of welding.

WELDING. Welding of High-Chromium Alloys. *Oxy-Acetylene Tips*, vol. 6, no. 9, Apr. 1928, pp. 172-177, 14 figs.

Survey of correct procedure for welding various types of these corrosion-resisting alloys; bronze-welding rustless iron; stainless steel, rustless or stainless iron; extra high-chromium alloys; castings.

CHROMIUM PLATING

Chromium Plating Applied Automatically, F. W. Curtis. *Am. Mach.*, vol. 68, no. 19, May 10, 1928, pp. 765-767, 5 figs.

Chromium plating of brake cams on production basis, by means of conveyor-type unit is being carried out by Chevrolet Gear and Axle Co. of General Motors Corp.; work started at loading station and transferred to acid-cleaning tank; water rinse; chromic-acid bath; plating solution consists chiefly of chromic acid and chromic sulphate.

CHROMIUM STEEL

WELDING. Welding Chrome Irons and Steels. *Iron Age*, vol. 121, no. 18, May 3, 1928, pp. 1242-1244, 3 figs.

It is necessary to prepare clean joint, use proper flux and strictly neutral flame of minimum dimensions, ending with properly adjusted heat treatment; heat treatment of welded joints; cutlery steels infrequently welded; rustless chromium-nickel irons give ductile welds; extra high chromium induces brittleness; castings should be welded hot.

DIE CASTING MACHINES

Die-casting Machines for Trial Parts. *Machy. (Lond.)*, vol. 32, no. 811, Apr. 26, 1928, pp. 97-101, 6 figs.

Rapid-acting single-cavity die-casting machine; burner for melting metal; pump forcing metal into die; die for producing part with thread; holding die shut; metal-tight connection between die and pump; extracting work; cooling die; die with interlocking core; supporting and locating die on machine; design of ejector; melting temperature of metals; keeping metal in proper condition; chute for conducting castings from machine.

DIES

SALVAGING. Salvaging Dies that Fail to Work, H. C. Charles. *Machy. (N. Y.)*, vol. 34, no. 9, May, 1928, pp. 656-657, 3 figs.

Dies changed to overcome faults; difficulties in bending U-shaped piece; example of die improved by slight changes; common error in designing bulldozer dies; wear that usually takes place at points that engage work and portions around which work is bent.

DURALUMIN

INTERCRYSTALLINE CORROSION. Corrosion Embrittlement of Duralumin—Practical Aspects of Problems, H. S. Rawdon. *Nat. Advisory Committee for Aeronautics—Tech. notes*, no. 282, Apr. 1928, 11 pp., 3 figs.

Investigation to develop methods of improvement and of protection which would assure reliability and permanence of duralumin as material for aircraft construction; intercrystalline corrosion by which tensile strength and ductility of sheet duralumin are very greatly affected; danger from embrittlement decreases as cross-section of duralumin increases; embrittlement is below surface; failure of ordinary coatings.

INTERCRYSTALLINE CORROSION. Corrosion Embrittlement of Duralumin-Accelerated Corrosion Tests and the Behavior of High-Strength Aluminum Alloys of Different Compositions, H. S. Rawdon. *Nat. Advisory Committee for Aeronautics.—Tech. notes*, no. 283, Apr. 1928, 38 pp., 16 figs.

Copper most closely related to susceptibility of duralumin to intercrystalline corrosion; microstructural aspects of corroded duralumin; X-ray useful for demonstrating existence of internal stresses; method of heat treatment important in determining behavior of material with respect to corrosion.

INTERCRYSTALLINE CORROSION. Corrosion Embrittlement of Duralumin—Effect of Previous Treatment of Sheet Material on the Susceptibility To This Type of Corrosion, H. S. Rawdon. *Nat. Advisory Committee for Aeronautics—Tech. notes*, no. 284, Apr. 1928, 24 pp., 10 figs.

Effect of variables of heat treatment of sheet duralumin upon its susceptibility toward intercrystalline corrosion; control of rate of quenching and avoidance of accelerated aging by heating are only means of modifying materials so as to minimize intercrystalline corrosive attack.

ELECTRIC FURNACES, FORGING

Electric Forge Furnaces at Fordson Plant, C. Longenecker. *Heat Treating and Forging*, vol. 14, no. 4, Apr. 1928, pp. 425-426, 4 figs.

Extensive use of electric-type furnaces for heating stock for upsetting in Fordson plant; in upsetting department, 24 electric furnaces for heating stock for forging, and four furnaces, for heat-treating products of upsetting machines; globar elements inserted above stock are supplied with current of 110 volts to 220 volts; hardening and drawing performed in furnaces designed by engineers of Ford Company.

ELECTRIC FURNACES, HEAT TREATING

Furnaces for Continuous Heat Treatment, W. C. Stevens. *Heat Treating and Forging*, vol. 14, no. 4, Apr. 1928, pp. 423-424, 2 figs.

Construction and operation of electric furnace for hardening small parts of quantity production; uniform results obtained; pusher type furnace; even heat distribution; pusher mechanism; automatic control obtained through pyrometers, necessary relays and contractors.

ELECTRIC FURNACES, HIGH FREQUENCY

Melting Sterling Silver in High-Frequency Induction Furnaces, R. H. Leach. *Am. Electrochem. Soc.—Advance Paper*, no. 20, for mtg. Apr. 26, 1928, pp. 223-227, 1 fig.

Operating data obtained from melting sterling silver in Ajax-Northrup furnaces at plant of Handy and Harman, Bridgeport, Conn.; performance of both oscillator and motor-generator types is given, as well as relative efficiency of air-cooled and water-cooled coil when used with generator type; summary of costs as compared with operation of oil-fired furnaces.

Steels Made Under New Conditions, F. Wever and H. Neuhaus. *Iron Age*, vol. 121, no. 16, Apr. 19, 1928, pp. 1073-1075, 6 figs.

Results of German tests with high-frequency induction furnace; carbonless, carbon and alloy steels show unusual properties; future possibilities; refining accelerated; steel bath, under normal refining slag, brought from 0.14 per cent carbon to 0.03 per cent in 2 minutes; carbonless steel made in high-frequency furnace. Abstract of paper published in Proceedings of Kaiser Wilhelm Institute for Iron Research.

ELECTRIC FURNACES, INDUCTION

Induction Furnaces (Les fours à induction), P. Beenet. *Jl. du Four Electrique (Paris)*, vol. 37, no. 4, Apr. 1928, pp. 117-118.

Evolution of induction furnace; feeding, construction details; power factor, conclusions and discussion.

Induction Furnaces (Les fours à induction), G. Ribaud. *Revue Trimestrielle Canadienne (Montreal)*, vol. 14, no. 53, Mar. 1928, pp. 1-15, 14 figs.

High-frequency induction or ironless induction furnaces; power factor, furnace types and description; advantages of high-frequency furnaces.

ELECTRIC FURNACES, IRON FOUNDING

Making Cast Iron in the Electric Furnace, C. E. Williams and C. E. Sims. *Franklin Inst.—Jl.*, vol. 205, no. 4, Apr. 1928, pp. 575-577.

Investigation completed by Bureau of Mines; involved year's successful operation of jobbing foundry making miscellaneous gray-iron castings from steel scrap.

ELECTRIC FURNACES, MELTING

Industrial Electric Heating, N. R. Stansel and E. F. Northrup. *Gen. Elec. Rev.*, vol. 31, no. 4, Apr. 1928, pp. 204-211, 10 figs.

Theory of Coreless induction furnace and its application to metal melting; factors which determine selection of frequency for coreless induction furnace for given melting service; selection of crucible for given charge. (To be continued.)

ELECTRIC FURNACES

DESIGN. Fundamental Principles in the Design of an Electric Furnace, T. Kawasakiya. *Inst. Elec. Engrs. of Japan—Jl. (Tokio)*, vol. 476, Mar. 1928, pp. 302-352, 11 figs.

Deals with general theory of design of electric furnaces and heating apparatus; tabulates results of experimental furnace which has been constructed according to calculated data.

MOLYBDENUM RESISTORS. Molybdenum-Wire Resistance Furnaces (Molybdaenwiderstandofen), P. W. Doehmer. *V. D. I. Zeit. (Berlin)*, vol. 72, no. 17, Apr. 28, 1928, p. 556, 1 fig.

Description of electric furnace designed on resistance principle in which molybdenum takes place of platinum as resistors and methyl-alcohol vapor is used to prevent evaporation of metal when at temperatures of 1300 to 1500 degrees Cent.; used for manufacture of molybdenum wire.

ELECTRIC FURNACES (Miguet)

The Miguet Electrode and the Miguet Furnace, M. Arrouet. *Am. Electrochem. Soc.—Advance Paper*, no. 36, for mtg. Apr. 28, 1928, pp. 351-354, 1 fig.

Describes type of commercial 10,000-kw. single-phase furnace, which is provided with new type of continuous electrode, called "Miguet Electrode," built by piecing together prebaked carbon segments assembled by dovetailing ends and by bolts in horizontal axis.

ELECTRIC HEATING, INDUSTRIAL

What is the Matter with Industrial Electric Heat?, T. P. Kindig. *Elec. World*, vol. 91, no. 17, Apr. 28, 1928, pp. 855-858.

It is claimed that billion-dollar load goes begging in electrical industry; study of existing conditions shows how power companies can cash in on enormous new-business possibilities.

FORGING, ELECTRIC

Electric Forging of Tappets Proves Successful, S. Stites. *Elec. World*, vol. 91, no. 18, May 5, 1928, p. 923, 1 fig.

Application of electric heat made at plant of Rich Steel Products Co. in connection with manufacture of tappets for automobile valves.

FORGE SHOP PRACTICE

Forging Machine Practice, W. S. Dewell, *Machy. (Lond.)*, vol. 32, no. 810, Apr. 19, 1928, pp. 73-75, 8 figs.

Motor car forgings with long upsets; dies for producing starting handle; two starting-handle forgings are not made exactly in accordance with rule 2, given in previous article; in making tie rod, unsupported stock is greater than can be generally upset at one blow; problem of arriving at fit between header and dies.

FURNACE

WALLS. Furnace Walls and Their Maintenance, W. J. May. *Mech. World (Manchester)*, vol. 83, no. 2153, Apr. 6, 1928, pp. 249-250, 5 figs.

Good silica brick and grouting used in contact with actual fire; air space where refractory linings are air cooled; iron supports for arches; smoothly pointed surface where exposed directly to heat; slag fusing on brickwork removed white hot; fire-work materials free from fluxing ingredients.

FURNACES, ANNEALING, CIRCULAR

Circular Annealing Furnace Produces Good Results, J. Strauss. *Foundry*, vol. 56, no. 8, Apr. 15, 1928, pp. 299-300 and 303, 6 figs.

Furnace erected in steel foundry department, U. S. Naval Gun factory; one-piece roof, 26 ft. in diam. overall and weighing about 25 tons; outlets for products of combustion arranged to permit close temperature control; burners supplied with fuel oil; flue construction; improvements secured from construction.

FURNACES, ANNEALING,

NORMALIZING. The Kathner Normalizing Furnace, C. P. Mills. *Heat Treating and Forging*, vol 14, no. 4, Apr. 1928, pp. 428-431, 4 figs.

Continuous-type gas furnace for sheets; special insulation reduces heat losses and improves quality of product; two independent sets of burners for use of oil when natural gas is not available; conveying mechanism; temperature control equipment; driving mechanism; performance in operation. Abstract of paper presented before Am. Soc. Mech. Engrs. and Engrs'. Soc. of West. Pa.

FURNACES, FORGING

The A. Finkl and Sons Company, W. Finkl. *Heat Treating and Forging*, vol. 14, no. 4, Apr. 1928, pp. 432-434, 8 figs.

Furnaces and furnace practice of Mid-West forge shops from early nineties to present day; box-type furnace with coke; oil as fuel; regenerators or checker rooms of furnace.

GAS FIRING. Designs Special Gas-fired Furnace to Heat Stock for Upsetting, R. C. Gorseau. *Iron Trade Rev.*, vol. 82, no. 19, May 10, 1928, pp. 1204-1205, 2 figs.

Unit features over and under firing from top and front; first cost is low and repairs prove economical; refractory life high; furnace designs for heating of tubular stock for upsetter, as well as heating nickel steel bar stock for upsetter work, representative operations on solid bar stock shown in tables.

PULVERIZED COAL. Forging Furnaces Operated with Powdered Coal, W. C. Rehfuss, *Ry. Mech. Engr.*, vol. 102, no. 5, May 1928, pp. 279-282, 8 figs.

Method has reduced maintenance costs and number of furnaces required; description of plant; early design of powdered-coal furnaces; trench-type powdered-coal forge; type of furnaces now used; advantages of new designs.

FURNACES, HEAT TREATING, GAS FIRED

Modern Gas-fired Heat-treating Furnaces, P. Hopkinson. *Machy. (Lond.)*, vol. 32, no. 810, Apr. 19, 1928, pp. 75-76, 3 figs.

Lining of furnace; question of furnace atmosphere of vital importance in heat treatment furnaces; vertical muffle-type furnace with preheating chamber introduced for heat treating long thin articles suspended vertically; surface combustion type of double oven furnace; gas-fired lead bath heated by surface combustion burners.

GEARS AND GEARING, BEVEL

HEAT TREATMENT. Heat-Treating Bevel Gears, C. S. Morgan. *Am. Mach.*, vol. 68, no. 17, Apr. 26, 1928, pp. 676-677, 11 figs.

Selection of special nickel steel and its heat treatment during various stages of manufacture of gear; method used by Chandler-Cleveland Motors Corp.; checking steel that forge shop will use; ring-gear forgings are made either from flat stock or from sections cut off billets; gears carburized for 8 hr. in oil-fired furnaces; single quench preferred.

HARDNESS TESTING INSTRUMENTS, PENDULUM

A Handy Hardness Tester. *Eng. Progress (Berlin)*, vol. 11, no. 4, Apr. 1928, pp. 117-118, 6 figs.

Tester "Duroscope" of von Leesen system is pendulum testing instrument which works on rebound principle; head of pendulum has spherical end, which, for ordinary workshop use in metal-working industries is made of hard steel, for ceramic and cement industries of tungsten-iridium, and for special testing purposes of diamond.

HARDNESS TESTING INSTRUMENT, ROCKWELL

Rockwell Hardness Tester Model 3-H. *Instruments*, vol. 1, no. 4, Apr. 1928, pp. 199-200, 2 figs.

Tester departs from all previous models in having heavier dead weight and fewer magnifying levers for impressing standard Rockwell loads; Vari-Rest provides means for supporting either tubular or bar stock or long flat sheets and many irregular shapes with support.

HARDNESS TESTS

Some Practical Notes on Hardness Testing. A. L. Walker. *Indus. Mgmt. (Lond.)*, vol. 15, no. 4, Apr. 1928, pp. 141-142.

Discusses few of numerous methods of hardness testing; advantages of Brinell machine; Firth hardometer; rebound test; impact test.

HIGH SPEED STEEL

A New Steel That Will Cut Manganese Steel, A. S. Martin. *Machy. (Lond.)*, vol. 32, no. 811, Apr. 26, 1928, p. 103.

Tests conducted on cutting capacity of Circle C steel, under ordinary shop conditions; cutting speeds and feeds that gave best results; heat treatment required for new steel; results obtained in tests.

TESTING. Discussion of paper by J. B. Mudge and F. E. Cooney Entitled, "Evaluating Quality in Heat Treated High Speed Steel by Means of Milling Cutter," G. C. Davis. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 5, May 1928, pp. 881-883.

Discussion of paper published in Feb., 1928, issue of Transactions. Presents table showing number of hours of service obtained from milling cutters hardened by means of salt bath.

HYDRAULIC PRESSES, FORGING

Hydraulic Forging Presses (Die hydraulichen Schmiedepresseinrichtungen), A. Deutch. *Foerdertechnik u. Frachtverkehr (Wittenberg)*, vol. 21, no. 5, Mar. 2, 1928, pp. 95-99, 9 figs.

Details of construction, pumps, valves, etc.; materials of construction and mode of operation; commercial types by Haniel & Lueg and others.

METALLOGRAPHY

ENGINEERING APPLICATIONS. Contributions of Scientific Metallography to Engineering (Was bietet die wissenschaftliche Metallkunde der Technik?), R. Schenck. *Zeit. fuer Metallkunde (Berlin)*, vol. 20, no. 3, Mar. 1928, pp. 93-103, 22 figs.

Discusses phenomena in pure metals; diagrams of state; thermal analyses, valuable properties of mixed-crystal alloys; influence of grain size, form and orientation of crystallites on technical properties; corrosion and its prevention.

METALLURGICAL PLANTS

Preliminary Considerations in the Development of Metallurgical Plants, H. M. Lewers. *Eng. and Min. Jl.*, vol. 125, no. 15, Apr. 14, 1928, pp. 609-611.

Important factor is actual grade of ore; dilution from wall rock makes larger tonnage of lower-grade ore than indicated by sample maps; advisable to break 100 tons or more of ore and ship to mill, sampling plant, or smelter; small variations in value of ore make larger variations in net operating returns; hypothetical case to illustrate; advice on other factors affecting design, construction and breaking in of plant.

METALS

COMPRESSION TESTING.—Plastic Compression, E. Siebel. *Metallurgist (supp. to Engineer, Lond.)*, Apr. 27, 1928, pp. 57-58.

Study of phenomena of flow under compression; in compression testing; difficulties are encountered, owing to tendency of ductile test pieces of requisite short length to assume barrel shape, while non-ductile test pieces fail by rupture along double shear cone; methods used should make it possible to study in detail exact flow which occurs in any given type of plastic deformation.

CORROSION. Corrosion and Protection of Metallic Surfaces (Attaque et protection des surfaces métalliques), E. de Winiwarter. *Revue Universelle des Mines (Liege)*, vol. 18, no. 3, May 1, 1928, pp. 130-145, 6 figs.

Examines cases of water corrosion and principles involved in corrosion; corrosion from acids and from electrochemical action; anti-corrosive coatings; processes of paint protection, gums, varnishes; modifying surface chemically; plating processes.

CORROSION. The Modern Slant on Corrosion. *Refrigeration*, vol. 43, no. 4, Apr. 1928, pp. 68-69.

Chemical aspect of corrosion; electrochemical corrosion; rust prevention.

CORROSION. The Corrosion of Metals, W. M. Guertler. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 5, May 1928, pp. 759-794, 30 figs.

Author discusses problem as it confronts metallurgist; basis of all commercial acid-resisting alloys necessarily must be group of elements, iron, nickel and copper; various elements that might be added to improve mechanical, electrical and other properties should be taken up by them in solid solution; explains that no one permanently durable alloy can ever be developed which will be resistant to all acids.

CORROSION. Method Evolved to Combat Corrosion, J. L. Dwyer. *Oil and Gas Jl.*, vol. 26, no. 46, Apr. 5, 1928, pp. 29 and 166, 6 figs.

Zinc plates in storage tanks with wires to tank roofs; same principle for pipes; method developed by R. Van A. Mills, petroleum engineer, U. S. Bur. Mines; said to have worked effectively in eliminating certain types of corrosion in oil field; calls for proper application of zinc electrodes at various intervals on equipment to be protected; improvement and new application of old zinc protection methods long used in other industries.

CORROSION. The Relative Corrodibilities of Ferrous and Non-Ferrous Metals and Alloys, S. N. Friend. *Iron and Steel of Can. (Gardenvale, Que.)*, vol. 11, no. 4, Apr. 1928, pp. 102-111, 12 figs.

Results of four years' exposure in Bristol Channel; tests ranging from four years upwards; direct comparison of relative resistance to various types of corrosions; losses in weight, depths of pitting, and reduction of tensile strength through corrosion correlated; sea-action tests; method of cleaning and examination of bars; corrosion of aluminum, copper, brass, lead, tin and zinc.

CORROSION. Notes on Metal Corrosion (Notes sur la corrosion des metaux), J. Jacquart. *Métallurgie (Paris)*, vol 60, no. 14, Apr. 5, 1928, pp. 17, 19 and 21-25, 4 figs.

Theories of corrosion; electrolytic theory; facts of corrosion; comparison of various ferrous metals, nonferrous metals and alloys; protection against corrosion.

CORROSION RESISTANCE. Effect of the Testing Method of the Determination of Corrosion Resistance, H. S. Rawdon and E. C. Groesbeck. *U. S. Bur. Standards—Tech. Paper*, vol. 22, no. 367, Mar. 6, 1928, pp. 409-446, 25 figs.

Determination of corrosion resistance of metals; tests were carried out on copper-nickel series, consisting of copper, nickel, and three copper-nickel alloys; methods tried out were simple immersion in non-aerated and aerated solutions, repeated immersion both continuous and intermittent, spray, and accelerated electrolytic test.

CUTTING. The Laws of Cutting Metals, J. A. Hall. *Mech. Eng.*, vol 50, no. 5, May 1928, pp. 414-415.

Review of German book by M. Kronenberg entitled, Grundzuege der Zerspanungslehre (Fundamentals of Theory of Metal Cutting), published by J. Springer, Berlin; throughout volume aim has been to put

conclusions in such shape that they will be of use to men in shop; problem of cutting speed is discussed and then laws of cutting pressure.

FORGING PROPERTIES. Behavior of Metals and Alloys in Forging, W. L. Kent. *Heat Treating and Forging*, vol 14, no. 4, Apr. 1928, pp. 393-398, 5 figs.

Investigations made on aluminum, copper and brasses are described showing properties of these materials during and after hot working; forging test as measurement of malleability at high temperatures investigated; mechanism of hot forging; effect of quenching hot-forged samples; effect of annealing cold-worked samples.

GAS DETERMINATION. Improved Rapid Method for Determining Gases in Metals, Especially Oxygen in Steel (Ein verbessertes Schnellverfahren zur Bestimmung der Gase in Metallen, insbesondere des Sauerstoffs im Stahl), W. Hessenbruch and P. Oberhoffer. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*. vol. 1, no. 9, Mar. 1928, pp. 583-600, 17 figs.

Development of hot-extraction process, and investigation of phenomena in connection therewith; improvements in apparatus during last two years and development of new process; reduction of pure oxides; comparison of different heat-extraction processes. 3-page bibliography.

PROPERTIES. British Institute of Metals Meeting. *Brass World*, vol 24, no. 4, Apr. 1928, pp. 110-111.

Report of papers presented at Annual meeting in London; brief description of papers by S. Beckinsale and H. Waterhouse, E. Griffiths and F. H. Schofield, R. Chadwick, F. S. Grimston, F. Hargreaves, W. L. Kent, W. A. Cowan, G. L. Bailey, A. L. Norbury, J. N. Friend, and T. Mathuda.

STRENGTH TESTING. Strength Testing of Metal Construction Materials Exhibited at the Berlin Exhibition of Engineering Materials (Die Pruefung der Festigkeitseigenschaften metallischer Baustoffe auf der Werkstoffschau), E. H. Rudeloff. *Giesserei (Duesseldorf)*, vol 15, nos. 12 and 13, Mar. 23 and 30, 1928, pp. 263-272 and 289-297, 42 figs.

Mar. 23: Hardness testers with dynamic stress; endurance tests. Mar. 30: Technological tests; device for wire testing; wear testing, etc. (Concluded.)

STRUCTURE. Discussion on "The Inner Crystal Structure of Some Native Metals," H. C. H. Carpenter, and S. Tamura. *Instn. of Min. and Met.—Bul. (Lond.)*, no. 283, Apr. 1928, pp. 1-16, 4 figs.

Additional data on iron, copper, silver, gold, antimony, bismuth and platinum, comparison with manufactured metals; photomicrographs.

STRUCTURE. The Inner Crystal Structure of Some Native Metals, H. C. H. Carpenter. *Metal Industry (Lond.)*, vol. 32, no. 16, Apr. 20, 1928, p. 405.

Deals with native antimony and bismuth and native platinum. (Concluded.)

SURFACE HARDENING. New process of Surface Hardening of Metals. The Cloud Burst Process (Un nouveau procédé de durcissement superficiel des métaux). *Pratique des Industries Mecaniques (Paris)*, vol. 11, no. 1, Apr. 1928, pp. 23-26, 9 figs.

Not a chemical process but based on surface

hardness from repeated blows; describes process and method of controlling hardness.

TESTING. Mechanical Testing of Metals, T. F. Russell. *Metal Industry (Lond.)*, vol. 32, no. 17, Apr. 27, 1928, pp. 417-420, 4 figs.

Fundamental load; strains and stress; strain diagrams. (Continuation of serial.)

TESTING. Three-dimensional Stresses in Mechanical Testing P. Ludwik. *Metallurgist (supp. to Engineer, Lond.)*, Apr. 27, 1928, pp. 63-64.

Author claims that even compression test, one of simplest of mechanical tests, cannot, in its usual form, be regarded as case of purely unidirectional loading; existence of three-dimensional stresses can account for well-known fact that internal stresses due to such causes as cold working, irregular heating, and so forth can cause sudden fracture in otherwise ductile materials. Abstract translated from Archiv fuer das Wisenhuettenwesen, Feb. 1928.

TESTING. The Importance of Three-dimensional Stresses in Materials Testing (Die Bedeutung raemulicher Spannungszustaende fuer die Werkstoffpruefung), P. Ludwik. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 14, Apr. 5, 1928, pp. 440-441.

Abstract of report no. 121 of Werkstoffausschusses des Verein deutscher Eisenhuettenleute, reprinted from Archiv fuer das Eisenhuettenwesen (Duesseldorf), vol, 1, no. 8, Feb. 1928, pp. 537.

X-RAY ANALYSIS. X-Ray Inspection in the Machine Shop, H. R. Isenburger. *Machy. (N. Y.)*, vol. 34, no. 9, May, 1928, pp. 649-652, 9 figs.

Ability of X-rays to penetrate materials increases with voltage, but decreases as atomic weight of materials increases; X-ray detects internal defects in castings; detailed pictures secured with ease and speed, so long as greatest thickness does not exceed 3½ inch of steel or its equivalent; cost of equipment required for X-ray inspection.

YIELD POINT. Safety Factor Required to Keep Static Stresses Below Yield Point (Ueber die Sicherheit gegen Ueberschreiten der Fliessgrenze bei statischer Beanspruchung), F. Schleicher. *Bauingenieur (Berlin)*, vol 9, no. 15, Apr. 13, 1928, pp. 253-261, 6 figs.

Theoretical discussion including compilation of experimental data on iron, steel and other ductile metals; application of theory to brittle materials and reinforced concrete.

STEEL

HEAT TREATMENT—CYANIDING. The Latest Practice of "Cyaniding" in Heat Treatment, J. W. Urquhart. *Mech. World (Manchester)*, vol. 83, no. 2153, Apr. 6, 1928, pp. 250-251.

Heat treatment of steels; salts in general use; uniformity of heating in lead; lead-tin bath; avoidance of surface oxidation; tempering; cyaniding baths; improved cyaniding bath; double quenching from cyanide bath; precautions in handling steel of manganese content exceeding 0.50 used in automobile practice.

HEAT TREATMENT, ELECTRIC. Hardening and Tempering by Electricity. *Heat Treating and Forging*, vol. 14, no. 4, Apr. 1928, pp. 400-404.

Heat treatment and application of electric heat as medium; various data gathered from

existing installations given for guidance in selecting equipment; explanation of metallographic terms; operating data; electric lead-pot furnace energy computation; tempering tool steel; types of electric furnaces. Abstract of serial report of Industrial Heating Committee 1926-1927, Nat. Elec. Light Assn.

FATIGUE STRESSES. The Fatigue-Resisting Properties of 0.17 per cent Carbon Steel at Different Temperatures and at Different Mean Tensile Stresses, H. J. Tapsell. *Iron and Steel Inst.—advance paper (Lond.),* no. 14, May 1928, 13 pp., 4 figs.

Review of behavior of mild steel under fatigue stresses over practical range of temperatures based on fatigue experiments carried out at National Physical Laboratory.

FINISHING. Conditions Encountered in Finishing Steel, W. S. Barrows. *Can. Foundryman (Toronto),* vol. 19, no. 4, Apr. 1928, pp. 27-28.

In preparation of carburized steel for plating many conditions of steel are encountered which are practically unknown to those who handle soft steels only; precautions intended to prevent defects actually decrease salability of article; marking causes cracks; grinding produces defects; detecting flaws before plating, absorption causes breakage; spot welding troublesome.

PROPERTIES. Recent experiments on the Cause of Hardness in Steel, Z. Jeffries. *Iron Age,* vol. 121, no. 16, Apr. 19, 1928, pp. 1102-1103.

Opinion that hardness of martensite is due to extremely fine grain of iron crystals and critical dispersion of carbide particles therein; martensite has many visual aspects; iron-carbon solid solution not very hard; age hardening of quenched steel. Abstract of paper read at Am. Soc. Steel Treating.

METALLOGRAPHY. The Application of Metallography to the Improvement of Steel (Die Anwendung der Metallographie zur Guetesteigerung der Erzeugung), H. Meter. *Stahl u. Eisen (Duesseldorf),* vol. 48, no. 16, Apr. 19, 1928, pp. 506-515, 26 figs.

Discusses size and distribution of ingot segregation in steels; variation in strength due to segregation, etc.; rolling conditions; secondary crystallization and strength properties; evaluation of structural steels; example is given of production of rail steel.

PROPERTIES. The Physical and Mechanical Properties of Steels, Their Significance and Their Relations, G. E. Troxell. *West. Machy. World,* vol. 19, no. 4, Apr. 1928, pp. 152-155 and 170, 3 figs.

Mechanical tests of steels; static tension test; compression tests; torsion tests for development of pure shearing stresses are conducted in special machines; impact tests coming into prominence; cold bend test; Rockwell hardness test; tests to determine endurance limit. (To be continued.)

TEMPERATURE EFFECT. On the Significance of the Proportional Limit of Steel at Elevated Temperatures, F. B. Foley. *Am. Soc. Steel Treating—Trans.,* vol. 13, no. 5, May 1928, pp. 813-822 and (discussion) 822-828, 6 figs.

Most valuable and most difficult value to determine is true elastic limit; author gives evidence from available data of straight-line relationships between temperature of testing and sum of two factors; namely,

strain produced at proportional limit and thermal expansion at temperature of testing.

TEMPERATURE EFFECT. The Strength of Steel at Elevated Temperatures, T. Mc. Jasper. *Mech. World (Manchester),* vol. 133, no. 2155, Apr. 20, 1928, pp. 294-295, 4 figs.

General impression among designing engineers that strength of steel at elevated temperatures for continuous operation is considerably more than it really is; corrosion rate of steel under stress is materially different from what it is under no stress. Abstract from paper read before Am. Petroleum Inst.

TENSILE OVERSTRAIN. Bending of Steel Overstrained by Tension, J. Muir and D. Binnic. *Metallurgist (supp. to Engineer, Lond.),* Apr. 27, 1928, p. 60.

Authors describe work undertaken to investigate effect of tensile overstrain on resistance of mold steel to compression; material used was carefully annealed 0.19 per cent carbon steel supplied in two bars. Abstracted from Jl. of Roy. Tech. College of Glasgow.

STEEL AIRCRAFT

CHROMIUM-MOLYBDENUM. Chrome-Molybdenum steel in Airplane Construction, J. B. Johnson, *Iron Age,* vol. 121, no. 16, Apr. 19, 1928, pp. 1076-1078, 6 figs.

Seamless tube most popular form of structural member; large moment of inertia obtained by using hollow sections of thin material; excellent weldability and air-hardening properties; impractical to heat treat welded structure by quenching on account of size of assemblies and slenderness of individual parts; excellent tension or compression joint; sheet chromium-molybdenum-steel fittings fastening together assemblies.

STEEL ANALYSIS

Dilatometric Analysis of Steel and Some Results of Dilatometric Heat Treatment, R. W. Woodward and S. P. Rockwell. *Am. Soc. Steel Treating—Trans.,* vol 13, no. 5, May 1928, pp. 795-811 and (discussion) 811-812, 10 figs.

By means of dilatometer certain fundamental constants may be obtained; from these it is proposed to classify steels according to their proper quenching medium; when lower quenching temperature is used it is often possible to brine-quench normal oil-quenching steels to give superior results.

STEEL, AUTOMOBILE

Automotive Steels, W. Naujoks. *Wis. Engr.,* vol. 32, no. 7, Apr. 1928, pp. 220-221, 238, 240 and 241.

Modern forging and heat treating practice; axles; steering knuckles, rear axle; connecting rods; camshafts and valves; crankshafts; steering arms; trend in spring steel has also changed in last few years.

MANUFACTURE. Manufacture of Steel for the New Ford, J. B. Nealy. *Blast Furnace and Steel Plant,* vol 16, no. 4, Apr. 1928, pp. 487-488, 4 figs.

Open-hearth, ingot-casting and soaking-pit operations; comments on fuel used and methods of combustion; transfer of ingots to mill; building housing open-hearth divided into three bays to accommodate stockhouse, charging floor and pouring aisle; soaking

pits arrange... taining four...

STEEL BA...

MANUFAC... Steel Bars b... cation des g... nage), J. C... *(Paris),* vol... 81, 5 figs.

Tests on... forging and... that superio... fact that in... treatment, v... least be an... above article...

STEEL C.S...

HEAT TR... the Heat T... Castings, A. ... *Assn.—Repri...* 14, 1928, pp...

Describes ... quenching a... steel castings... 500 tons per... of about one-...

SHRINKAG... Castings, Ko... *lurgist (supp...* 1928, pp. 55...

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Factors inf... ing to great... influence of... metallurgical... sand casting... writer state... fluences and... certain lines... profitable re...

STEEL IN...

DEFECTS,... led before C... centrale bla... Viteaux. *Gé...* Apr. 7, 192...

pits arranged in six blocks, each block containing four holes.

STEEL BARS

MANUFACTURE. Manufacture of Large Steel Bars by Forging or Rolling (La fabrication des gros ronds par forgeage ou laminage), J. Courtheoux, *Revue de Métallurgie (Paris)*, vol. 25, no. 2, Feb. 1928, pp. 76-81, 5 figs.

Tests on bars from rolls; comparison of forging and rolling methods; author claims that superiority of rolled metal is due to fact that in its best quality it requires no treatment, whereas forged metals must at least be annealed. See also comment on above article, by E. de Loisy, p. 81.

STEEL CASTINGS

HEAT TREATMENT. A Modern Plant for the Heat Treatment of Miscellaneous Steel Castings, A. W. Lorenz. *Am. Foundrymen's Assn.—Reprint*, no. 28-10, for mtg. May 14, 1928, pp. 141-152, 9 figs.

Describes plant, uniquely equipped for full quenching and tempering of miscellaneous steel castings; with this plant output of over 500 tons per month may be obtained, at cost of about one-half cent per pound.

SHRINKAGE. The Construction of Steel Castings, Koerber and Schitzkowski. *Metallurgist (supp. to Engineer, Lond.)*, Apr. 27, 1928, pp. 55-56.

Investigation of shrinkage phenomena in castings carried out at two steel foundries in Duesseldorf district; relates not only to measurement of contraction in simple test bars but also to study of actual casting and especially of large wheels and pulleys. Abstract translated from Stahl u. Eisen, Feb. 2 and 9, 1928.

STEEL FOUNDRY PRACTICE

Steel Foundry Practice, A. D. Kirby, *Mech. World (Manchester, Eng.)*, vol. 8, no. 2157, May 4, 1928, pp. 326-328, 1 fig.

Deals with this subject in three parts; sands used, method of molding, and manufacture of steel; oil-sand cores for steel casting; molding boxes; runner details; wheel blanks; making ordinary tee-pipe; vent wire in steel foundry; methods of strickle work. Paper read before Newcastle sec. of Inst. British Foundrymen.

Variables in Steel Foundry Practice, F. A. Melmoth. *Am. Foundrymen's Assn.—Reprint* no. 28-21, for mtg. May 14, 1928, pp. 323-358, 9 figs.

Factors influencing production of steel casting to greatest extent are: human element; influence of various molding operations; metallurgical behavior of steel in form of sand casting; heat treatment after casting; writer states his impressions of these influences and considers where, in his opinion, certain lines of investigation exist which offer profitable results.

STEEL INGOTS

DEFECTS. White Spot in Steel Ingots Rolled before Complete Solidification (La tache centrale blanche dans les lingots d'acier), Viteaux. *Génie Civil (Paris)*, vol. 92, no. 14, Apr. 7, 1928, pp. 333-335, 10 figs.

Treats of center white-spot formation obtained when ingot is rolled before its solidification; some examples of white spots in rails.

HETEROGENEITY. Second Report on the Heterogeneity of Steel Ingots. *Iron and Steel Inst.—advance paper (Lond.)*, no. 1, May 1928, 147 pp., 35 figs.

Report of Committee, dealing with ingot molds; certain features of steel manufacture which may influence heterogeneity; study of nickel, nickel-chromium and nickel-chromium-molybdenum steel ingots; carbon steels other than "killed;" interim report on researches at Sheffield University and Glasgow Royal Technical College. Bibliography. See abstract in Engineering (Lond.), vol. 125, no. 3252, May 11, 1928, p. 583.

STEEL PLATES

STRESSES. The Stresses in Flat Plates, H. H. Gorrie. *Rensselaer Polytechnic Inst.—Eng. and Science Series*, Apr. 1928, pp. 20-60, 29 figs.

Results of investigation to determine variation in intensity of strains that occur in flat steel plates subjected to uniform loads, to determine actual principal axes of strain for various points on plate, and by actual measurement, and from theoretical considerations, to find strain along these axes. Bibliography.

STRIP MILLS

COLD ROLLING. The Cold-Rolling of Strip Steel, H. C. Uhl. *Iron and Steel Engr.*, vol. 5, no. 4, Apr. 1928, pp. 171-177 and (discussion) 177, 12 figs.

Advantage of cold rolling; uses of cold rolled strip steel; classification as to quality and finish; preparation for rolling; trend in new mills; description of mills and method of rolling, electrical equipment for cold-rolled strip steel mills; motors and control; motor sizes required for various sizes of mills; drives for reels.

TESTING MACHINES

TENSION. Improved Motor Driven Tensile Strength Tester. *Instruments*, vol. 1, no. 4, Apr. 1928, pp. 209-210, 1 fig.

Tester constructed on desk-type; 1/6-hp. General Electric constant-speed motor mounted on base and connected directly to speed reduction unit by flexible coupling; sealed mercury-to-mercury contact switch through which current is fed; tester especially adapted for thin metal sections; calibrated up to maximum capacity of 500 lbs., elongation scales and recorders can be supplied.

UNIVERSAL. Universal Testing Machine With Pendulum Dynamometer, Dial Gauge, and Driving Gear in Base-Plate. *Eng. Progress (Berlin)*, vol. 11, no. 4, Apr. 1928, p. 123, 1 fig.

Gripping devices for tensile test pieces are located between two uprights in such way that heating furnace can be conveniently accommodated in case test pieces are to be heated; forces are taken up by central crosshead which is situated between compression and tension sections of machine and transmitted to pendulum dynamometer by system of levers; manufactured by Mannheimer Maschinenfabrik Mohr & Federhaff.

News of the Chapters

STANDING OF THE CHAPTERS

D URING the month of May there were 142 new and reinstated members, while 117 were lost through arrears, resignations and deaths, leaving a net gain for the month of 25 members. The total membership of the Society on June 1, 1928 was 5059.

Membership standing of the society as of June 1, 1928, is as follows:

GROUP I		GROUP II		GROUP III	
1. Detroit	489	1. Los Angeles	154	1. New Haven	99
2. Chicago	452	2. Hartford	144	2. Washington	79
3. Pittsburgh	377	3. Golden Gate	126	3. Worcester	79
4. Philadelphia	334	4. Lehigh Valley	123	4. Tri City	77
5. Cleveland	310	5. Milwaukee	120	5. Rockford	66
6. New York	309	6. Canton-Mass.	112	6. Southern Tier	56
7. Boston	265	7. Dayton	110	7. Providence	56
		8. St. Louis	109	8. Columbus	55
		9. Cincinnati	106	9. Rochester	53
		10. Indianapolis	99	10. Toronto	50
		11. Syracuse	90	11. Schenectady	43
		12. Buffalo	77	12. Springfield	40
		13. Montreal	76	13. Fort Wayne	36
		14. North-West	59	14. Notre Dame	32

GROUP I—The seven chapters in this group maintained their same positions as last month. Detroit and Chicago both showed a gain, while Pittsburgh, Philadelphia and Cleveland showed small losses, with New York and Boston presenting gains.

GROUP II—Los Angeles increased its lead over Hartford to ten members, Los Angeles having had a net gain of seven members for the month. Dayton had 136 members on last month's report and was in position three, while this month Dayton showed a loss of 26 members which now places them in position seven. This heavy loss is accounted for by seven resignations and 19 dropped for arrears. This month also is the anniversary of the month in which this chapter was organized. Golden Gate in a tie last month with Milwaukee for fourth place now is in position three. Lehigh Valley with a net gain of eight has been advanced to position four from position six last month. Canton-Massillon with a gain of two advanced from seventh to sixth position. St. Louis, Cincinnati, Indianapolis and Syracuse remain the same although all showed gains. Buffalo with a net gain of six advanced from thirteenth to twelfth place. The largest gains in this group were shown by Lehigh Valley with eight; Los Angeles with seven and Buffalo with six.

GROUP III—New Haven with a gain of six now has a comfortable lead

of 20 members over Washington in second place. Worcester with a gain of three advances from fourth position to third, passing Tri City and going into a tie with Washington for position two. Providence with 56 is in a tie for sixth place with Southern Tier. Columbus with a loss of three drops from sixth position last month to eight, permitting Southern Tier and Providence to advance. Fort Wayne with a loss of four members dropped a position lower than on the last report.

The new suggested grouping as discussed last month brought in several replies, some favorable and some unfavorable. As a matter of comparison, we are printing the suggested new grouping as it would appear this month. The basis for division is

Group I includes chapters with membership of 200 or over
  II   100 or over
  III   60 or over
  IV   under 60

GROUP I			GROUP II	
1. Detroit	489		1. Los Angeles	154
2. Chicago	452		2. Hartford	144
3. Pittsburgh	377		3. Golden Gate	126
4. Philadelphia	334		4. Lehigh Valley	123
5. Cleveland	310		5. Milwaukee	120
6. New York	309		6. Canton-Mass.	112
7. Boston	265		7. Dayton	110
			8. St. Louis	109
			9. Cincinnati	106

GROUP III			GROUP IV	
1. Indianapolis	99		1. North West	59
2. New Haven	99		2. Southern Tier	56
3. Syracuse	90		3. Providence	56
4. Washington	79		4. Columbus	55
5. Worcester	79		5. Rochester	53
6. Buffalo	77		6. Toronto	50
7. Tri City	77		7. Schenectady	43
8. Montreal	76		8. Springfield	40
9. Rockford	66		9. Fort Wayne	36
			10. Notre Dame	32

BOSTON CHAPTER

The annual meeting of the Boston Chapter was held at the Massachusetts Institute of Technology, Cambridge, Mass., on Friday, May 4, 1928. A special dinner, served in Walker Memorial, brought out many of the older members who have not been frequent attendants of late. Following the dinner the annual report of the secretary-treasurer was given and the officers for the coming year were elected, as follows: chairman—Harrison B. Parker, Trimont Mfg. Co.; vice-chairman—Robert S. Williams, Massachusetts Institute of

Technology; secretary-treasurer—Howard E. Handy, Saco-Lowell Shops.

The retiring chairman, Leslie D. Hawkridge, addressed the Chapter and reviewed the past year's work, referring particularly to the educational work. After especially commending those who had carried on the work in connection with the educational course in metallurgy, he made suitable presentations to the lecturers and to the secretary of the Chapter. The meeting was then turned over to chairman-elect, Harrison B. Parker, whose compliments of the excellent work of the retiring chairman during the past year brought a rising vote of thanks from the Chapter members.

T. Holland Nelson, of the Chrome Alloy Products Co., Conshohocken, Pennsylvania, was the guest speaker of the evening, his subject being "Chromium-Iron Alloys." Mr. Nelson described the development of the rustless irons and steels in both Europe and America and discussed the common uses to which the alloys are put. He presented a series of slides showing the properties and uses of the material, one of the most interesting applications being the recent large installation at the plant of the DuPonts. The talk was followed by considerable discussion from the floor and J. J. Jupenlatz, chairman of the Springfield Chapter presented a written discussion accompanied by slides. The attendance at the meeting was over one hundred.

The May meeting concluded the work of the Boston Chapter for the year, no more meetings being scheduled until fall. Dr. G. B. Waterhouse succeeds Dr. Williams as chairman of the Program Committee and plans are already under way for the technical program next winter and for the Annual Outing in September. "Vic" Homerberg again heads the Educational Committee and at the May meeting outlined his plans for the coming season. To make the year's work a success a great deal of co-operation is needed from the members in general, and the officers would appreciate it if any member who would like to serve on a committee would get in touch with either the chairman or the secretary.   *H. E. Handy.*

BUFFALO CHAPTER

At 6:30 p. m., May 31, 1928, the annual dinner was served at the Hotel Statler to fifteen members, after which Chairman McCarthy introduced the speaker, A. J. Huston of the Iroquois Gas Corp., whose paper the "Application of Gas to the Metal Industry" proved very interesting and much discussion followed.

Chairman McCarthy asked for the report of the secretary, who read the financial report and a summary of the meetings of the past year. The report also showed a gain of 19 members, nine of which are sustaining, the first in the Chapter's history.

Herbert J. Cutler, chairman of the nominating committee, reported the following nominations for officers for the year 1928-29: chairman—Bishop Clements; vice-chairman—Robert E. Sherlock; secretary—F. L. Weaver and treasurer—John H. Birdsong. Members of the executive committee: B. L. McCarthy, A. D. Potts, W. S. Miller, W. H. Blocksidge, H. J. Cutler, W. C. Peterson, and Wm. T. Casey.

As there were no other nominations, Mr. Blocksidge moved that nomination be closed, seconded by Mr. Higgs, carried. Mr. Roof moved that the secretary cast one vote for the nominees as reported by Mr. Cutler, seconded by Mr. Higgs, carried. *F. L. Weaver.*

CANTON-MASSILLON CHAPTER

The last meeting of the Canton-Massillon Chapter until the fall was held May 17, 1928 at the Canton Club, Canton, Ohio. This meeting was featured with a dinner at which 70 members and guests were present. As its guest speaker, J. P. Gill, metallurgist of the Vanadium-Alloys Steel Company, gave a very interesting and absorbing talk on tool steels, chemical compositions, and effect of alloys thereon. After this splendid talk, moving pictures were shown of the last Dempsey-Tunney fight, and of several World War films taken by the U. S. Signal Corps.

During the past year the Chapter has apparently stood still in membership. However, no concentrated effort was made to obtain new members, but effort was made to sell the present members. We feel that the coming year will see the Canton-Massillon Chapter materially increase its membership. *R. Sergeson.*

CLEVELAND CHAPTER

The second annual outing of Cleveland Chapter was held at The Country Club on Friday, May 18th, 1928. A varied program of sports, including golf, baseball, and horse shoe pitching was enjoyed by about ninety members and guests. The tennis matches scheduled were called off on account of wet grounds. Over $150.00 worth of prizes were awarded the winners of the different events. The men in charge were as follows: Golf—J. W. Kelley; Baseball—D. M. Gurney; Horseshoe Pitching—R. E. Kerslake.

The club professional, Joe Mitchell, assisted by Charles Backhauer, acted as general sports directors.

Our fellow members, Ray Bayless and Henry Vlchek acted as photographers and succeeded in following and recording the progress of the sports events. These films will be shown at one of our regular meetings this fall.

The big event of the day was the special country club dinner served under the direction of F. J. Pittenger, club manager, which was enjoyed by about eighty members and guests. During this dinner the crowd was entertained by Carl Monahan, who certainly knows how. The Chapter greatly appreciates his kindness and a vote of thanks is hereby extended to him.

Chairman H. H. Smith presided at the meeting which followed the dinner and called on various speakers for remarks. Among the speakers were Prof. H. M. Boylston, Joe Emmons, Ray Bayless and Chairman of the Outing Committee, W. H. White.

The secretary-treasurer's report was made by J. S. Ayling and membership committee report by D. M. Gurney. Following these reports the newly elected officers were installed and the meeting turned over to Chairman D. M. Gurney.

Despite the showery weather which acted to replace swimming events the "spirits" of the crowd never failed and everyone voted the outing a great success.

The Chapter wishes to express its appreciation to Charles Stark, president of Penton Publishing Co., for acting as sponsor for the outing and to the following companies who generously contributed prizes: The American Fork & Hoe Co., The Atlas Steel Co., The W. S. Bidle Co., The Carpenter Steel Co., The Cleveland Metal Treating Co., The Cleveland Twist Drill Co., Cleveland Wire Div. of General Electric, The Case Hardening Service Co., The Firth-Sterling Steel Co., The Ferry Cap & Set Screw Co., The Fairmount Tool Co., The J. W. Kelley Co., Lamson & Sessions Co., The Lakeside Steel Improvement Co., The Ridge Tool Co., Thompson Products, Inc., Vlchek Tool Co.

J. S. Ayling.

COLUMBUS CHAPTER

The Columbus Chapter held its regular monthly meeting Tuesday evening, April 17, 1928, at the Fort Hayes Hotel. The regular meeting was preceded by a good fellowship dinner.

Harold F. Wood, chief metallurgist, Wyman-Gordon Co., Harvey, Illinois, was the speaker of the evening. Mr. Wood's subject was "Drop Forgings and their Scientific Development." He first discussed the early history of drop forgings, and then the selection of the proper steel. Inspection of the steel was the next point discussed and the importance of this point stressed because good forgings and especially good crankshafts cannot be made of steel with pipes or nonmetallic inclusions in it or small ruptures. Mr. Wood then discussed steels that are easiest forged and the steels that are the hardest to forge. The next point was the design of the forging and after that the die problems for this particular forging. Next, the importance of the size of stock was discussed; in this connection Mr. Wood stated that a big thick flash was a line of weakness in the hardening of forgings, and many times if this is not controlled the forging will crack along the line where the flash is trimmed off. Heating of stock and careful regulation of temperature was the next point discussed, forging temperatures being very important. Heat treatment of forgings then came in for its discussion, this being important because forgings are sold on physical properties. Mr. Wood told how all these things were controlled in the Wyman-Gordon plant by making the laboratory part of the production department. Mr. Wood's paper was illustrated with lantern slides and was very enthusiastically received by the members.

The meeting closed with a rising vote of thanks to Mr. Wood and the Wyman-Gordon Co. for this splendid paper.

G. D. Moessner.

The Columbus Chapter held its regular monthly meeting Tuesday evening, May 15, 1928, in the ballroom of the Fort Hayes Hotel.

Election of officers was the first business to be taken up, and the following were elected: S. Z. Krumm, Buckeye Steel Casting Co., chairman; R. E. Christian, Columbus Bolt Works, vice-chairman; G. D. Moessner, Buckeye

Steel Casting Co., secretary and treasurer. The executive committee: R. T. Dawson, Jeffrey Mfg. Co.; E. B. Furry, Ralston Steel Car Co.; O. B. Jones, Jeffrey Mfg. Co.; H. B. Kinnear, Marion Steam Shovel Co.; G. S. McFarland, consulting engineer; H. A. Mitchell, Bonney-Floyd Co.; B. C. Theil, C. & G. Cooper Co.; and Professor John Younger, Ohio State University. The financial report was read and approved.

The speaker of the evening was W. R. Flemming, metallurgist, The Andrew Steel Co., Newport, Ky. He spoke on open-hearth steel practice, and his talk was very much appreciated by all present.

The second feature of the evening was a 4-reel motion picture of The United Mills of Sweden by The Kloster Steel Co., Chicago. This picture is exceptionally interesting showing crucible, open-hearth, bessemer and electric furnace steel making, also hollow drill steel manufacture and the making of Lancashire iron and charcoal. Mr. Lindeblat of The Kloster Steel Co. was with us, and answered questions about the picture. Both he and Mr. Fleming were given a rising vote of thanks for this enjoyable evening.

<div align="right">G. D. Mocssner.</div>

DAYTON CHAPTER

The regular monthly meeting of Dayton Chapter was held Monday evening, May 21, at the Engineer's Club. The feature of the evening was the new 5-reel motion picture of the United States Bureau of Mines, "The Story of Iron". This film pictured the prospecting for iron ore in the great ranges of the Lake Superior district and near Birmingham, the various methods of open-pit and underground mining and the transportation of the ore to the Lake Superior docks. At the lower lake ports the unloaders were shown removing the cargo from the hold of the boat and transferring it to the stock piles or to the blast furnace. Close-up views of a large blast furnace were shown, including charging with the skip hoist, opening the tapping hole with an oxygen jet, and the molten iron running into the transfer ladles. The picture concluded with views of an old-fashioned pig bed and the modern pig casting machine.

At the conclusion of the picture the first annual business meeting and election of officers was held. Following the reports by the retiring chairman, secretary and treasurer the following officers for the next fiscal year were elected: chairman—J. B. Johnson, chief, material branch, Wright Field; vice-chairman—R. R. Kennedy, research laboratory, National Cash Register; secretary—F. M. Reiter, Industrial Gas Division, Dayton Power & Light, Co.; treasurer—L. H. Grenell, research laboratory; Frigidaire Corporation.

<div align="right">F. T. Sisco.</div>

DETROIT CHAPTER

On Saturday, May 19, the Lansing group of the Detroit Chapter held a meeting at Michigan State College, East Lansing. R. S. Archer, research metallurgist for the Aluminum Company of America, was the principal speaker of the evening. In spite of the lure of the out-of-doors, fifty members and friends attended the meeting, and twenty-seven were at the dinner, which

was held at the Union Building. The meeting was held in the assembly room of the Engineering Building immediately after the dinner.

G. W. Bissell, Dean of Engineering, welcomed the visitors on behalf of the College and reminded them of the part that Michigan State College is playing in supplying the metallurgical profession with recruits by offering a course to undergraduates in industrial metallurgy. Jim Hays of the Michigan State College Dairy Department presented a new type of cow which would supply cheese, butter, and ice cream without the intermediate difficulties. His talk was very entertaining.

Mr. Archer's subject was "The Development of Aluminum for the Automotive Industry". He discussed various aluminum alloys which are most successfully forged, cast, die-cast, and extruded. He exhibited articles made by the different methods. The slides showed the different physical properties of different aluminum alloys and illustrated graphically why these alloys harden. The stiffness or modulus of elasticity was convincingly shown between aluminum alloys hardened and as-rolled, and steel of the same cross-section as the aluminum and aluminum of the same weight as the steel. The advantage of aluminum in structural work was discussed, and its applications to automobiles, street cars and railway locomotives. Mr. Archer presented his material so convincingly that all of us were ready to believe that the aluminum age would probably soon supplant the steel age.

The discussion which followed lasted until an hour that was unbecoming for Sunday morning. *Frederick G. Sefing.*

GOLDEN GATE CHAPTER

The May meeting of the Golden Gate Chapter was held jointly with the local group of the American Welding Society on Wednesday, May 9, at the Athens Athletic Club, Oakland. This being the annual meeting, the secretary's report was read and approved.

The following officers and executive committee were elected to serve for the following year: Dr. W. J. Crook, chairman; Clyde Williams, vice-chairman; H. E. Morse, sec'y-treasurer; executive committee members—C. Hawley, G. E. Batten, J. S. Fowler, D. H. Grubb, W. Grothe, Ivan Johnson, H. J. F. Niemann, E. E. Fess, J. V. Coulter, S. H. Edwards, C. M. Henderson, J. R. Gearhart.

Following the business session short talks by members of the chapter on selection of automotive steels, selection of tool steels, selection of methods for steel castings. These were given by E. E. Jamison, S. H. Edwards and Ivan Johnson in the order named. Each of these talks was short, concise, to the point and "full of meat" from the beginning to the end. They were much appreciated by the attendance.

Dr. Crook then turned the meeting over to Mr. Atkinson of the American Welding Society, who introduced K. V. Laird. Mr. Laird presented a paper on "Welds at High Temperatures". The talk was extended by the use of slides and graphs.

Macro and micrographs were shown, taken from sections in and adjacent to the weld before and after rupture. Comparisons were made between test specimens ruptured at room temperature and at 960 degrees Fahr.

It was a very interesting and instructive paper, and was the result of a great amount of labor and ingenuity. The paper, in full, will be published in the American Welding Society *Transactions* at an early date, as part one of the investigation.   *S. E. Thurston.*

HARTFORD CHAPTER

The May meeting of the Hartford Chapter was held on Tuesday, the 8th, at the Hartford Electric Light Auditorium, the speaker being Ray Cook, works manager of the Wallace Barnes Company of Bristol. Mr. Cook described spring manufacturing in all of its phases, particularly those of heat treatment and inspection. Many of the unusual automatic devices used by Wallace Barnes were explained. The discussion centered on heat treating and raw materials used in spring making.

The results of the election of chapter officers for 1928-1929 was announced from the letter ballot sent in by the members: chairman, John C. Kielman, New Departure Mfg. Co.; vice-chairman, Edson L. Wood, Lander, Frary and Clark Co.; secretary and treasurer, Henry I. Moore, Firth-Sterling Steel Co.

On Tuesday, June 5th, the Hartford Chapter closed its 1927-1928 activities with its eighth annual banquet which was served at the City Club. About 150 members and guests attended. David Nemser, the retiring chairman, introduced A. H. d'Arcambal as toastmaster. All of the past chairmen of the chapter were seated at the speaker's table along with Fred G. Hughes, national president; D. L. Brown, works manager of the Pratt and Whitney Aircraft Co., and Charles M. Pond, manager of the Pratt and Whitney Small Tool Works. After the New Departure orchestra and the Colonial Quartet had entertained with musical selections which met with everyone's hearty approval, Charles T. Olin, publicity director of the New Departure Mfg. Co. of Bristol, was introduced to talk on ''Co-operation Won't Do It''. Mr. Olin is a veteran newspaper man in Connecticut. The title of his subject was more to start his listeners thinking than for him to follow, and for an hour and a quarter Mr. Olin told in a forceful way how ''Co-operation Will Do It,'' and left many excellent thoughts with the audience, interposing many humorous reminiscences of his newspaper work. To close the evening, the Reverend George B. Gilbert of Middletown, Connecticut, who is Episcopal Missionary in Middlesex County, delivered a most unusual and absorbing description of his experiences in the domestic mission field of Connecticut within fifty miles of Hartford. A good many members thought the program committee had played a mean trick by including a minister in the list of speakers, and that they would be bored by some dry talk, but for an hour Mr. Gilbert kept the audience roaring with laughter with the stories of occurrences in his work. Covering an area of one hundred square miles and trying to relieve suffering among the poor for the past thirty years, Mr. Gilbert has had an experience which is filled with absorbing human interest stories.

The combination of Mr. Olin's subject and Mr. Gilbert's descriptions met with unanimous approval of the members who left at a quarter of twelve well fed, well entertained and well pleased with the 1928 banquet.

                                                              R. Stanton.

LEHIGH VALLEY CHAPTER

The second annual dinner meeting of the Lehigh Valley Chapter of the American Society for Steel Treating took place Tuesday, June 5, 1928, at the Elks Club in Phillipsburg, N. J. In spite of the fact that we had a very rainy night, there was an excellent turnout, there being more than one hundred and fifty members and guests present. The large number of guests present is an indication that there is a growing interest in the Society and its activities among men of this district not at present officially connected with it.

The meeting was opened by Chairman L. J. MacGregor who announced the results of the recent election of officers and members of the executive committee for the next year. W. L. Trumbauer of the Bethlehem Steel Company was elected chairman; John Howe Hall of High Bridge, N. J., vice-chairman, and H. V. Apgar of Easton, Pa., was elected secretary-treasurer. The executive committee will be composed of Messrs. A. C. Jones of Lebanon; O. V. Greene of Reading; F. B. Martin of Easton; G. V. Luerssen of Reading; G. Douthett of Easton; Bradley Stoughton of Lehigh University, Bethlehem; E. H. Hollenback of Bethlehem; J. K. Killmer of Bethlehem, and L. F. Witmer of Easton.

Following the announcement of the election results the newly elected chairman was introduced and the meeting turned over to him. Chairman Trumbauer expressed his appreciation of the honor conferred upon him by the members of the Chapter, and stated that he knew the Chapter members would be expecting big things from the new group of officers and executive committeemen and he intended to make it his business to see that they were not disappointed. The other newly elected officers and members of the executive committee were then introduced at the meeting.

The principal speaker of the evening was Dr. F. C. Langenberg, vice-president of the Climax Molybdenum Corporation and metallurgist of the U. S. Army Watertown Arsenal. Dr. Langenberg, who is regarded as an old friend of the Lehigh Valley Chapter, this being the sixth consecutive year he has spoken to the Chapter since its organization, gave a very interesting and instructive illustrated talk on ''Metallurgical Progress.''

At the opening of his talk only the high spots of which may be given here, Dr. Langenberg stated that he was merely going to give his own personal viewpoint on the progress of metallurgy, and that it was to be taken for what it was worth. A few basic metallurgical facts and theories were stated concerning the structure of steel and its hardening, and he said considering the vast amount of material written on the subject not a great deal of real progress has been made recently in coming nearer to the true theory of the hardening of steel. ''Temper brittleness'' was discussed, it being another phenomena, the real answer to which is at present unknown. The process of hardening with ammonia was discussed and Dr. Langenberg pointed out certain valuable uses to which it could be put when the process was more developed and had been made practicable.

The fact that the world's tin supply was rapidly diminishing was pointed out, together with the fact that this opened up a vast field for the development of a thoroughly practical rust resisting stainless steel.

The impact test, Dr. Langenberg told us, was becoming more and more important every day, and that he believed that when results of certain experiments now in progress, with impact and tensile tests, became generally known, that it, coupled with the tensile test, would become a vital part of a great many exacting specifications.

Following Dr. Langenberg's address a motion picture film entitled "Letting Dynamite Do It" was shown through the courtesy of the E. I. Du Pont De Nemours Company. The film was a very interesting one from the beginning to the end, giving vivid pictures of the vast power of dynamite and the many and varied uses to which it may be put.

Music before and during the dinner was furnished by Morton Towle and his "Valley Chapter Six Merrymakers". Numerous familiar songs were heartily sung by the members, led by the orchestra and Mr. Towle, producing generally a merry and jovial atmosphere. All in all the second annual dinner meeting was a huge success and "Here's for many more like it."

T. D. Shannahan.

LOS ANGELES CHAPTER

The May meeting of the Los Angeles Chapter of the American Society for Steel Treating was held Thursday, May 10, at Frank Wiggins Trade School in the City. Dinner was served in the banquet room at 6:30 p. m. The dinner was prepared by the students in the cooking school and was an excellent dinner. There were ninety-one members and guests present.

After the dinner was served, the regular annual election of officers was held. Wade Hampton was re-elected chairman; James H. Spade was elected vice-chairman and H. V. Ruth was re-elected secretary. The executive committee consists of the following: Professor W. Howard Clapp, Messrs. W. S. Grau, Ralph R. Hall, Thomas Hutton, W. H. Laury, H. J. Barton, C. A. Stiles and Joe R. Cooke.

Immediately following the election of officers, annual reports were rendered by the treasurer, membership chairman, program chairman and convention chairman. The reports were interesting, and the work of the committees was very highly appreciated by the members.

We had as one of our guests Kein Holtz, director of vocational education of the City of Los Angeles. After the routine business of the meeting, Kein Holtz gave a most interesting talk on vocational education. He told us of the many difficulties encountered when the vocational idea was young, and of the marvelous accomplishments that had been made in the past few years. He spoke of the co-operation which existed between industry and the vocational schools, and also told the chapter members that it was his hope that soon there would be a heat treating class with a fully equipped laboratory at the Frank Wiggins Trade School. We all trust that this hope will soon materialize into a reality, and are confident that there will be many students from the Los Angeles chapter of the American Society for Steel Treating who will register in the class.

After the talk by Kein Holtz, we were all conducted through the school. There are ten full floors of equipment, and the basement holds the classes in

masonry and tile setting. It was the wish of most all the members that the Los Angeles chapter would again have the privilege of visiting this marvelous school.

<div align="right">*H. V. Ruth.*</div>

MONTREAL CHAPTER

The annual meeting of the Montreal Chapter was held on May 19 in the Banquet Hall of the Windsor Station with a record attendance of more than two hundred. As most of the metal working industries in the Montreal district were represented it is illustrative of the increasing interest that is being taken in the local chapter, and shows great promise for the third year.

Robert Job, vice-president of Milton Hersey Co., Montreal, was elected chairman, and there is no doubt that his election was a very popular one. Mr. Job is associated closely with both of the railways in Montreal, and under his guidance the chapter should grow rapidly.

Other officers elected were: vice-chairman, F. H. Williams, assistant test engineer, Canadian National Railways; treasurer, Gordon Sproule, lecturer, McGill University; secretary, D. G. MacInnes, associate editor, Engineering Times, and executive committee, Robert J. Noakes, superintendent, Canadian Pneumatic Tool Co., T. C. McConkey, superintendent and vice-president, B. J. Coghlin Co.; W. J. Hall, Montreal manager, Production Materials, Ltd., and John K. Schofield, secretary-treasurer, Edgar Allen and Co. (Canada), Ltd.

Following the reports of the secretary and treasurer, the evening was devoted to a smoker and entertainment. The entertainment committee, consisting of Mr. Schofield and Ralph B. Norton, excelled itself, because there was sufficient good and varied entertainment to last all night. However, after three hours of dancing acts, boxing bouts, vocal and musical numbers, the party closed officially, and will be remembered by steel treaters and mechanical men in Montreal as one of the finest meetings they have ever attended.

PHILADELPHIA CHAPTER

FINAL MEETING OF TEMPLE METALLURGY CLASS AND ALUMNI ASSOCIATION

The conclusion of another successful school year for the Temple Metallurgy Class was celebrated on Friday, May 25th, by a most enjoyable and instructive meeting, held jointly by the class and the Metallurgy Class Alumni Association.

At 1:00 p. m. the two groups assembled at the Philadelphia Navy Yard for a tour of inspection of the United States Naval Aircraft Factory, under the guidance of Horace C. Knerr, director of the course, and his trusty lieutenants Messrs. Downes and Kennedy. The inspection trip covered all departments of the factory and included a detailed investigation of the many interesting operations necessary to produce the flying boats. Outstanding features of interest were the fabrication of wings employing built-up truss construction of heat treated, high tensile ferrous and nonferrous alloys, as compared to the old style construction employing plywood and other types of wood: the physical testing laboratory, where a pull test on a cast aluminum alloy was made for

the benefit of the visitors: the manufacture and packing of parachutes: and the fabrication shop where a number of ships were in course of construction, while a number of others were undergoing repairs.

Upon leaving the Navy Yard at 5:00 p. m. the party motored to the Engineers' Club, where all enjoyed a good dinner attended by informal discussion of the trip. After the dinner a recess was held in the lounge of the Club to afford an opportunity for the members of the 1928 class to join the Alumni Association.

At 8:00 p. m. a business meeting of the Association was held. After a brief discussion relative to the aims and plans for the future of the course, during which short talks were made by a number of guests, the following officers were elected for the coming year: C. M. Gottschau, chairman; H. R. Schmidt, vice-chairman; A. M. Lindsley, secretary; A. K. Edwards, treasurer; and directors, Messrs. Ziegler, Fox, Nielsen, Jeffries and MacLean.

At the conclusion of the business meeting a most interesting motion picture lecture on the Manufacture and Use of Abrasives and Refractories was presented by Mr. Wells, of the Carborundum Co. of America.

In closing, the members of the 1928 class tendered to Mr. Knerr, his associates and the Philadelphia Chapter, a vote of appreciation for the hard work and unfailing interest which has made possible this comprehensive course in the heat treatment and metallography of steel.   *A. M. Lindsley.*

ROCHESTER CHAPTER

The last Executive Committee meeting of the year was held at 5:50 p. m. on May 14 at the Hotel Osburn with all members present. At the close of this meeting a dinner, at which the speaker and several other guests were present, was enjoyed.

At 8 p. m. the last regular meeting of the season convened in the Assembly Hall with an attendance of about 18 members and guests. Following a short business session with the annual reports of the secretary-treasurer, nomination, election and installation of officers and members of the executive committee, Mr. Wattel, newly elected chairman, took the chair, and introduced the speaker, H. B. Eynon, secretary and general manager of the Pure Carbon Co., Wellsville, N. Y. His subject was "Manufacture of Carbon Brushes and Carbon Specialities".

Mr. Eynon first stated that carbon was an element, but not metallic, and occurred in the form of coal, charcoal, lamp black, graphite and the diamond. Carbon will not melt, and is more or less nonabrasive. In the process of manufacture coke which has been ground to approximately two hundred mesh flour is mixed with coal tars which form a bond. It is then forced through dies for required shapes and then baked.

Carbon is made into many shapes for brushes, disks, projector lamps, search lights, telephones, dry cells, B-batteries, flash lights, etc.

After the talk a lively discussion followed, Mr. Eynon answering all questions to the satisfaction of those present.   *H. J. LeClaire.*

ROCKFORD CHAPTER

The eighth and last meeting of the Rockford Chapter for the season was

held Friday evening, May 11, in the Venetian Room at the Nelson Hotel. Fifty members and guests attended the 7 o'clock dinner, which preceded the meeting.

Chairman Swan Hillman opened the business meeting at 8 p. m. and the minutes of the previous meeting were read and approved.   The slate of officers named by the nominating committee was unanimously elected. The new officers are as follows:

R. M. Smith, chairman; C. C. Crain, vice-chairman; George R. Monks, secretary-treasurer.   Executive committee members—Alfred Lien, Fred Hockman, Freeman Anderson, Duncan P. Forbes, Harold J. Stein.

At the close of the business meeting, O. T. Muehlemeyer, retiring secretary and treasurer, who has held office in the Rockford Chapter for the past seven years, was presented with a Fyrac spotlight as a token of appreciation of the work he has done for the Rockford Chapter.   Swan Hillman, retiring chairman, and an officer for the past three years, was presented with a cigar lighter in appreciation for his services to the Rockford Chapter.

The speaker of the evening was H. E. Scarbrough, industrial heating specialist for the General Electric Co.   His topic was ''Electricity as a Source of Energy for Heat Treating.''   In his talk, the speaker gave comparisons on costs and operations of electric, gas and oil furnaces.   Typical installations of electrical equipment were illustrated with numerous slides. The talk was very interesting and the slides showed installations of some very large equipment as well as smaller units.

The meeting adjourned at 9:45 p. m. with a rising vote of thanks to the speaker.   *H. W. Gustafson.*

SCHENECTADY CHAPTER

The annual meeting of the Schenectady Chapter was held on Tuesday evening, May 22 at the Riverwood Inn.   Dr. S. L. Hoyt, chairman called the meeting to order and appointed C. F. Marquis and G. R. Brophy as tellers to count the ballots for election of officers for 1928-1929.   The following were elected: Chairman—Professor M. F. Sayre, Union College; vice-chairman—James Taylor, American Locomotive Co.; secretary-treasurer— F. P. Coffin, General Electric Co.

The following were also elected to act on the executive committee: Dr. S. L. Hoyt, chairman program committee; B. T. Perry, chairman sustaining membership committee; W. L. Ruder, chairman entertainment committee; J. G. Hicks, chairman meetings committee; Wm. F. Hodges, B. H. Magill and J. K. Haynes, membership committee; and Charles F. Marquis and C. B. Buxton, fellowship committee.

The meeting was then turned over to the new Chairman, Prof. M. F. Sayre who introduced C. L. Ipsen who spoke to the members present on ''New Development in Welding.''   The next speaker of the evening was Dr. S. L. Hoyt who gave a talk on ''Tool Steel.''   Considerable discussion on both these subjects was indulged by all present.

Entertainment was given by Mr. Boyd of the American Locomotive Co. in the form of a monologue entitled ''The Vicar of Wakefield.''

A rising vote of thanks was given to Dr. S. L. Hoyt for his good work as chairman for the past year.   *James Taylor.*

ST. LOUIS CHAPTER

The regular monthly meeting of the St. Louis Chapter was held on Friday evening, May 18, 1928, at the American Annex Hotel. The meeting was preceded by an excellent chicken dinner and entertainment, after which the meeting was called to order by the chairman and the minutes were read and approved.

The nominating committee presented the following names of members, who were unanimously elected to serve as officers for the coming year: chairman, W. E. Remmers, Professor, Washington University; vice-chairman, J. E. Kilzer, Davis Boring Tool Co.; secretary and treasurer, Carl G. Werscheid, Colonial Steel Co. Executive committee: W. D. Thompson, Laclede Gas Co.; E. H. Meyers, Western Cartridge Co.; O. Moody, St. Louis Screw Co.; R. B. Hieye, Century Electric Co.; Harry Lape, Ludlow-Saylor Wire & Iron Co.

The speaker of the evening, J. C. C. Holding, manager, American Stainless Steel Co., gave an excellent paper, the subject being "Stainless Steel, its Characteristics, History and Applications."

All in all it was a very successful meeting and a lively discussion followed Mr. Holding's paper and talk.

The meeting was adjourned with a rising vote of thanks to J. C. C. Holding and his company in coming and talking to us at this time, as we feel greatly indebted for this modern subject.   *C. G. Werscheid.*

TORONTO CHAPTER

The chapter was fortunate, at its May meeting, to hear Jordon Korp, of the Leeds and Northrup Co., Philadelphia, on "Tool Design, Heat Treatment and Its Relation to Production". A large number of members were present and much interest was exhibited in Mr. Korp's talk, which was of a thoroughly practical nature, based upon long and intimate experience as a steel treater. In the earlier part of his talk, the speaker allocated due portion of their responsibilities to the tool designer, the machine shop and the steel treater, and pointed out that, no matter how important was the part played by the steel treater, the onus was not upon him alone. His were the last hands through which the tools passed, and very often the blame for failure was upon him, although the failure was due to no fault of his. Drawings should contain definite instructions for the guidance of the steel treater. In fact, these instructions to the steel treater were as important in high class work as were the ordinary dimensions for the guidance of the die-makers.

The subject dealt with the three phases of heat treating, namely, the heat, the quench, and the temper, and the importance of time temperature and uniformity of conditions were emphasized. A point which the speaker dealt with, and one with which his audience was visibly impressed was the color phenomena of temperature. The whole subject has gone too far for steel

treaters to place reliance any longer on the color indication. Only the use of instruments which gave accurate readings to temperature would eliminate the errors that had grown out of arbitrary methods of estimating temperature. Rate of heating was also of vital importance and had to be given full consideration, otherwise the whole process would be vitiated.

The speaker dealt at considerable length upon the time necessary for proper heat treatment and deplored the all-too-regrettable desire of certain people to "rush the job". The surest way to wreck a specimen was to rush it through the furnace to the quench without allowing the heat to penetrate to the heart of the section. Mr. Korp sketched out the rate curve for heat penetration into a specimen and emphasized the temperature lag between the outer surface and the core. The speaker dealt also with heating above the critical range, and said that steel treaters had difficulty in appreciating the fact that the critical range was not stationary under all heating conditions but varied considerably.

W. O. Oliver, of the Swansea, Toronto works of the Steel Co. of Canada, was elected chairman of the Toronto Chapter at the regular meeting held in the Consumers' Gas Co. auditorium, 55 Adelaide St. East, Toronto, May 18. A. Lowry was elected vice-chairman, L. F. Fitzpatrick, secretary, and A. G. Davis, treasurer. A. G. Blair is chairman of the executive committee, which consists of the following—N. P. Peterson, J. W. McBean, James A. Harris, T. H. Young, Cliff Cornwall.

TRI-CITY CHAPTER

The May meeting of the Tri-City Chapter of the American Society for Steel Treating was held at the Peoples Power Company's auditorium in Moline on May 24th. At this meeting Mr. Deuble, metallurgist for the Central Alloy Steel Co., Canton, Ohio, talked on "Defects in Steel." Mr. Deuble's talk covered such points as defects in steel that occur at the mill and defects that occur at the plant where the steel is used; the latter being a result largely of improper heat treatment. Mr. Deuble also pointed out methods of detecting these defects and he spent some time discussing the deep etch test. Quite a lengthy discussion followed Mr. Deuble's talk.

Following the meeting lunch prepared by the program committee was served to about forty-five members and guests.　　　*George A. Uhlmeyer.*

We are indeed sorry to record the death of Jacob Trautman, Jr., a well-known member of the Society, who, until recently, has lived in Pittsburgh.

Mr. Trautman has been identified with the Colonial Steel Co., Pittsburgh, ever since it was organized 25 years ago. About a year ago he became manager of the Pacific coast territory for the Colonial Steel Company. Prior to that he was general sales manager at Pittsburgh. Mr. Trautman was prominent in the affairs of the American Society for Steel Treating, having acted as general chairman of committees for the Pittsburgh Convention of the Society in 1923. Mr. Trautman died June 2, 1928, being 53 years of age.

Items of Interest

R OBERT M. Bird, past president of the A. S. S. T., has been named district manager in the New York office of the Midvale Co., Philadelphia, succeeding Ward A. Miller. Mr. Bird graduated in mechanical engineering from Lehigh University in 1902, was associated with the Bethlehem Steel Co., from 1902 to 1924. He served successively as superintendent of its heat treatment department, superintendent of the Lehigh mills and as chief metallurgist and engineer of tests of the Bethlehem plants. During the past four years, Mr. Bird has been associated with George F. Pettinos, as production and operating manager of sand operations and graphite mills along the Atlantic coast. He is a member of various technical organizations.

Jerome Strauss, formerly with the United States Naval Gun Factory, Washington, is now with he Vanadium Corporation of America at Bridgeville, Pa.

The Firth-Sterling Steel Co., McKeesport, Pa., has recently issued a booklet describing ''Circle C'' Steel for cutting the harder metals. It is stated that tools made from this steel are capable of cutting high-manganese, high-carbon steels.

A recent leaflet of the Driver-Harris Co., Harrison, N. J., describes Nichrome castings for case carburizing and other heat treating processes.

Philipp Moll, formerly sales manager of C. H. Boehringer Sohn, Hamburg and Nieder-Ingelheim on Rhine, and more recently with Dissoway Chemical Co., has become associated with The Roessler and Hasslacher Chemical Co. as assistant to manager of sales.

Spencer Turbine Co., Hartford, Conn., has issued an 8-page bulletin illustrating turbo-compressors for foundry cupolas. It is claimed that close control of blast is obtained with these units operated by electric motors.

The viscosity, as well as the composition, undoubtedly is a factor in determining the relative desulphurizing powers of blast furnace slags. Few investigators have attempted to measure the viscosity of blast furnace slags, due to difficulties encountered in making such determinations at temperatures existing in the blast furnace. Feild and Royster in the Bureau of Mines Technical Paper 157 described the torsion viscometer used by them in their investigation of viscosities of blast furnace slags. In order to have another method for determining viscosities of blast furnace slags to check results obtained by means of the torsion viscometer, investigators at the North Central Experiment Station of the Bureau of Mines, Minneapolis, Minnesota, constructed a capillary viscometer entirely of graphite. The results obtained on a number of slags indicated that the capillary type of the viscometer is more accurate within certain ranges than the torsion viscometer.

Important standardization activities in many American industries during the past twelve months are described in the year book of the American Engineering Standards Committee, recently issued. Forty-nine new standards and 40 new projects are listed for numerous branches of industry and engineering, including mechanical, civil, electrical, mining, wood, textiles and safety.

The discovery or the development of the best processes and practices possible with present-day knowledge, and the extension of these, as standards, to all branches of industry is cited in the year book as the object of the standardization movement. The American Engineering Standards Committee has adopted 111 national standards up to the present time and is now working on 164 other standardization projects, according to the year book.

Continual contact is maintained by the American Engineering Standards Committee with the 19 national standardizing bodies in foreign countries, the year book says, with the constant exchange of standards and specifications. The Committee receives daily many requests from abroad for American standards or for information about standards in use here.

Copies of the year book may be obtained on request to the American Engineering Standards Committee, 29 West 39th Street, New York.

Between 60 and 70 scientists and fuel technologists in eleven different countries, it is announced, have tentatively accepted invitations to speak at the Second International Conference on Bituminous Coal which will be held at the Carnegie Institute of Technology in Pittsburgh, during the week of November 19, 1928. The list includes about forty Europeans whom Dr. Thomas S. Baker, president of the Carnegie Institute of Technology, personally invited while making his recent two-month's visit in Europe in the interests of the coal conference.

The purpose of the coming congress, the announcement points out, is similar to the one held in 1926 by the Carnegie Institute of Technology: to present the results of recent studies of coal that have to do with improved methods of utilization and combustion. The program will include the discussion of low temperature distillation, high temperature distillation, coal tar products, power, smokeless fuel, complete gasification of coal, hydrogenation, pulverized fuel and its new applications, fixation of nitrogen, coal beneficiation, etc.

The Botfield Refractories Co., Swanson and Clymer Sts., Philadelphia, announces that the distribution of its products in the Toledo and Ohio vicinity will be handled by the Builders and Industrial Supply Co., 4090 Detroit St., Toledo, Ohio.

The Veeder Mfg. Co., of Hartford, Conn., manufacturers of small counting machines and die castings has recently been merged with the Root Co., of Bristol, Conn., manufacturers of heavy duty counters, hinges and stampings. The newly formed company will be known as Veeder-Root, Inc.

The Steel Castings Development Bureau has recently been formed by a group of Eastern foundries. Through this bureau users or probable users of steel castings can consult with the technical advisors of the bureau on problems relating to the use or application of castings. Offices of the bureau are at 500 Stock Exchange Bldg., Philadelphia.

Employment Service Bureau

This bureau is for all members of the Society. Want ads will be printed at the following rates: minimum of 30 words $0.50; each additional word $0.02.

This service is also for employers, whether members of the Society or not. Rates for this service are as follows: minimum of 50 words $1.00; each additional word $0.02. Fee must accompany copy.

Address answers care of AMERICAN SOCIETY FOR STEEL TREATING, 7016 Euclid Ave., Cleveland, unless otherwise stated.

POSITIONS WANTED

METALLURGICAL ENGINEER. Technical graduate experienced in pyrometry, heat treating, foundry, automotive practice, microscope, steel manufacture, testing, research and sales. Capable of handling men and producing results. Address 6-20.

TOOL HARDENER: Experienced in heat treating, carburizing, hardening carbon and alloy steels, lead and cyanide work. References furnished. Address 7-5.

POSITIONS OPEN

TOOL HARDENER, experienced in the heat treatment of small dies for forming work. Must be able to do pack hardening and have some knowledge of Electric Hump Furnace. Opportunity to connect with high-grade firm. Address 6-10.

WANTED: Engineering graduate from the class of '26 or '27 desirous of entering sales engineering work in heat treating and drawing fields. Thorough knowledge of electric furnaces and temperature control equipment gained through training period. Considerable traveling. Answer in full giving age, education, schools attended and experience. State salary expected and enclose snapshot or photograph. Personnel Department, Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia.

METALLURGIST: To work directly under the direction of the plant metallurgist in a company manufacturing high grade open-hearth, electric and crucible steels. Must have technical training and steel plant experience. Address 7-15.

The Clearing House
For the Sale of Used Equipment

		1 time	2 times	3 times	4 times
Rates per Insertion	1 inch[1]	$ 4.50	$ 4.25	$ 4.20	$ 4.00
	2 inch	8.50	8.00	7.75	7.50
	3 inch	12.00	11.50	11.25	11.00

[1]There are 12 lines to an inch. A charge of 40 cents per line will be made for extra lines.

FOR SALE: LEITZ MICRO-METALLOGRAPH

An opportunity now prevails to purchase at the most attractive price the latest model of the Leitz ''Micro-Metallograph,'' complete with accessories, in perfect condition and guaranteed throughout. Address 7-10.

FOR SALE: 1 Hoskins F. B. No. 235—5 tube combustion furnace complete with switch board, transformer, etc. 220-110 volts, A. C. Used approximately six months. American Malleables Co., Owosso, Mich.

The address of the North American Mfg. Co., manufacturers of oil burners and blowers, has been changed from 8918 Frederick Ave., Cleveland, to 2910 E. 75th St.

The Gaskill Industrial Furnace Corp., Warren, O., has issued a bulletin on preheated air recuperative melting furnaces for melting ferrous and non-ferrous metals and alloys. Oil, gas or powdered coal may be used.

One of the primary factors in the rate of elimination of silicates from open-hearth steel is the size of the particle formed on deoxidation. If excess silicon is added to a medium or high-carbon steel very small glassy particles are formed which rise slowly out of the steel. On the other hand, if there is sufficient iron oxide or manganese oxide to flux the silica, a rapid increase in rate of elimination is found due to the increased size of the silicate particle.

From the results of laboratory work on deoxidation with silicon performed by the United States Bureau of Mines it is possible to predict just what type of inclusion will be formed with any silicon addition to any type of open-hearth steel, provided manganese is not added at the same time. Predictions from the laboratory work have been checked on various open-hearth heats and out of 67 steel samples studied only six samples showed types different from that predicted. These results make it possible to designate the optimum amount of silicon to add to any open-hearth heat in killing in the furnace and show that if clean steel is desired certain grades of steel should be killed in the furnace with silicon and manganese rather than silicon alone. Investigation of the properties of the manganese silicates thus formed is now in progress.

Titanium is a well known component of bauxite ores, sometimes occurring in sufficient quantity to make its recovery worth considering. This question has been raised by some of the companies lixiviating bauxite ores. In Serial 2867, by Will H. Coghill, recently issued by the United States Bureau of Mines, there are given the results of a study of the waste sludge discharged daily at a large plant in East St. Louis, Illinois. This daily discharge of waste sludge contains over 75,000 pounds of titanium dioxide. The paper also contains data regarding the titanium content of various bauxite ores studied by the Bureau at its Southern Experiment Station, Tuscaloosa, Alabama.
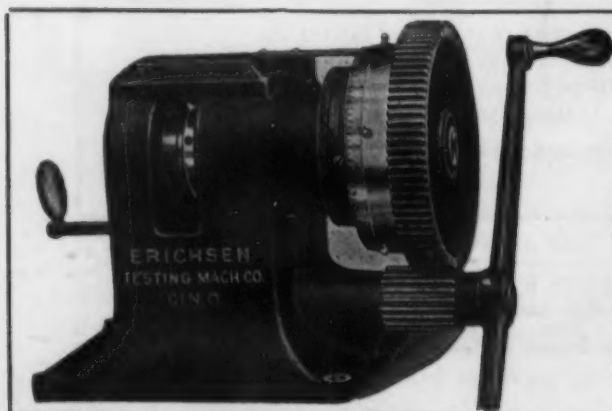
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